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DRAFT REPORT

DATA EVALUATION AND PRELIMINARY STUDY DESIGN

FOR THE

COMMENCEMENT BAY NEARSHORE/TIDEFLATS SUPERFUND PROJECT

NOVEMBER 1983

PREPARED FOR:
STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY

CONFIDENTIAL

TETRA TECH

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By

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INTRODUCTION

Tasks 3 and 4 of the EPA/WDOE Cooperative Agreement for the Commencement Bay Superfund Project require a determination of the type and extent of contamination in the Commencement Bay Nearshore/Tideflats area, description of the pathways and fates of contaminants, determination of contaminant sources, and characterization of sources as current or historical. This report presents the results of a Phase I study, which forms the basis for all field investigations to be conducted under Tasks 3 and 4. The objectives of Phase I are: 1) to review and evaluate all existing data for the project area (Commencement Bay waterways and the Ruston shore) and potential reference areas; 2) to identify data gaps in the spatial and temporal coverage of previous studies; and 3) to provide a preliminary study design for the field investigations.

An overview of the data evaluation and study design procedure is depicted in Figure 1. Initially, information was gathered, reviewed, and evaluated with respect to its acceptability for inclusion in the Commencement Bay project data base. Data not meeting the acceptance criteria were rejected and were not considered in subsequent evaluations. After organization by kind of study, acceptable data were evaluated for information content, where information content is a measure of the adequacy of the data to describe contaminant concentrations or effects spatially and temporally throughout the study area. Based upon the information content of the acceptable existing data, data gaps are identified and described. Finally, the Decision Criteria are applied to the data gaps in the design of additional studies to provide additional data necessary to accomplish program objectives.

This report is organized into two major sections: Data Evaluation and Study Design. In each major section, subsections are arranged by kind of study under the categories of Physical Processes, Contaminant Sources, and Contamination and Effects. The next sections summarize the procedures used in compiling and evaluating data.

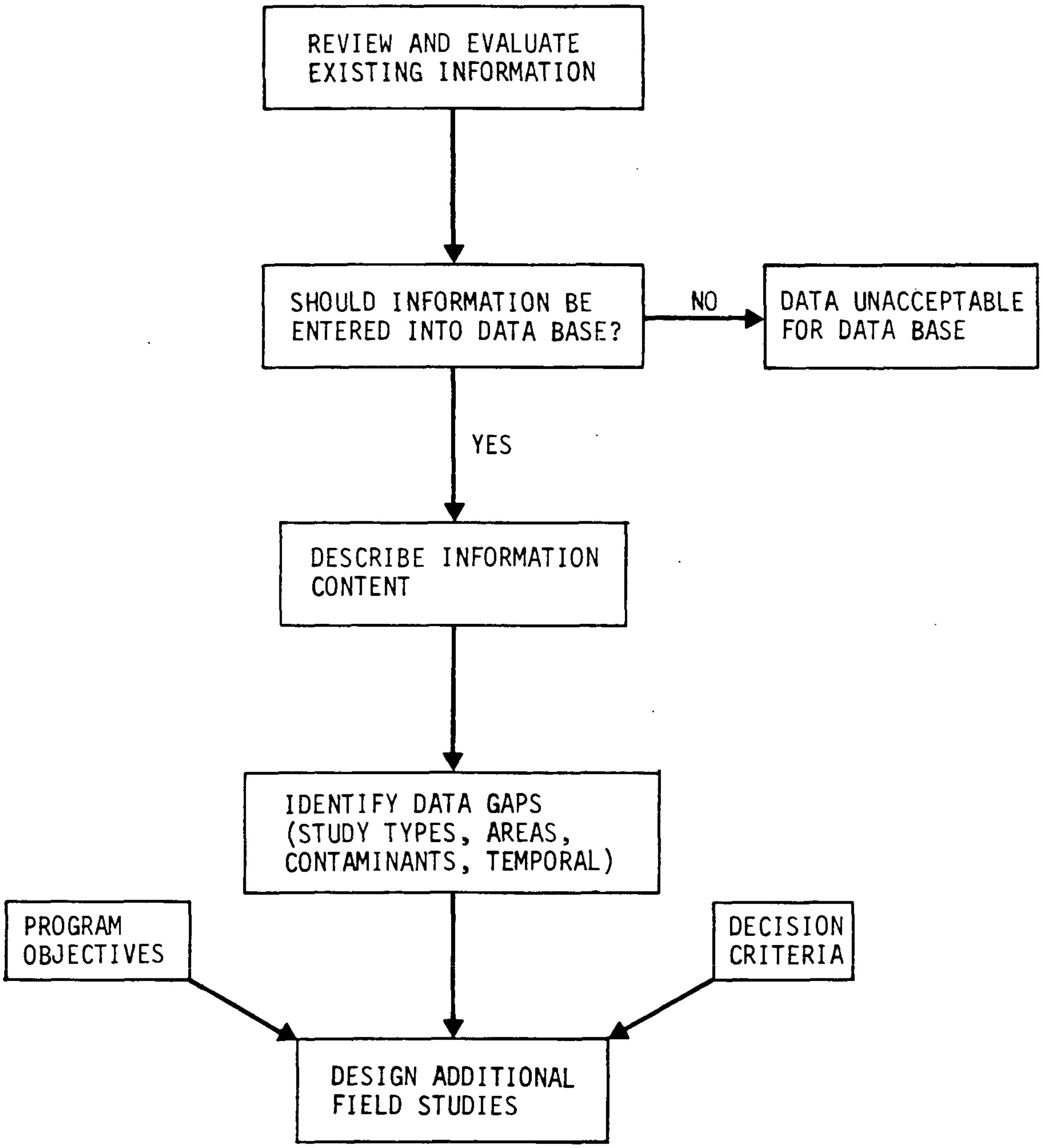


Figure 1. Tasks 3 and 4 - Data Evaluation and Study Design Procedure.

DATA EVALUATION

DATA COMPILATION

All relevant data from the study area and from potential reference areas were collected and reviewed. Information was compiled from the WDOE library (Lacey), the EPA Region X library, the University of Washington library system, the Tetra Tech library, WDOE files (Lacey and Southwest Regional Office), Port of Tacoma files, files of the Tacoma-Pierce County Health Department, files of Puget Sound Air Pollution Control Agency, and personal contacts with scientific investigators (WDOE, COE, EPA, NOAA, UW). The following criteria were used for determining which documents were to be included in the review process: 1) the document had to contain some information on the study area (defined as Commencement Bay waterways, the Puyallup River as far upstream as the Interstate 5 highway bridge, and the Ruston Shore); i.e., studies of only the deepwater (greater than 60 ft depth) portions of Commencement Bay or only reference areas were not reviewed in detail; 2) Documents that were not already present in the Tetra Tech library had to be available within the short time period allocated to data compilation and evaluation.

After the initial compilation of data, relevant documents were entered into a Commencement Bay information library. At the same time, a record of each document was cataloged and entered into the files of the Record and Document Management System.

DATA EVALUATION PROCEDURE

The following sections describe the methods used in evaluating data with respect to its suitability for entry into the data base on the study area. Standard evaluation procedures were developed to ensure as objective an evaluation as possible.

Format

The available information was classified into 15 categories according to type of study and environmental media. These study categories were:

PHYSICAL PROCESSES

- Circulation

SOURCE DATA

- Point discharges
- Runoff sources
- Contaminant input from spills
- Groundwater sources
- Atmospheric sources

CONTAMINATION AND EFFECTS

- Sediment quality
- Water quality
- Bioaccumulation
- Pathology
- Fish ecology
- Benthic invertebrate ecology
- Phytoplankton ecology
- Zooplankton ecology
- Bioassay effects

Note that source data were defined relative to sources of pollutant inputs to the waterways or areas along the Ruston shoreline. Ecological studies on plankton, fish, and benthic invertebrates were reviewed primarily for information on the abundance and distribution of indigenous organisms.

The kind and amount of information contained in each document was summarized on a "Data Evaluation Form" (Figure 2). Coding of the forms

DATA EVALUATION FORM

COMMENCEMENT BAY - WDOE STUDY

AUTHORS: ____________ DOCUMENT NO.: ____________

____________ DOCUMENT DATE: ____________

TITLE: ____________

SPONSOR / INDUSTRY: ____________

TYPE OF STUDY: ____________ SOURCE / SINK: ____________

NO. SUBAREAS: ____________ NO. REFERENCE AREAS: ____________

NO. STATIONS: ____________

NO. SAMPLES: ____________

SAMPLING FREQUENCY: ____________

NO. SUBSTANCE / CONTAMINANT GROUPS: ____________

DATA QUALITY ASSESSMENT

A = ADEQUATE I = INADEQUATE N = NO DESCRIPTION

ITEM	A/I/N	COMMENTS
SAMPLE COLLECTION		
SAMPLING HANDLING/STORAGE		
QA/QC		
ANALYTICAL METHODS		
DETECTION LIMITS		

STUDY ACCEPTABLE FOR DATA BASE? YES NO

DATA CONSISTENCY ASSESSMENT

	ADEQUATE? A/I/NA	COMMENTS
SPATIAL COVERAGE		
TEMPORAL COVERAGE		
CONTAMINANTS		

AREA		CP	ME	VO	BN	AE	PC	PE	WQ	TOTAL NO. STATIONS
PROJECT	HY									
	BL									
	SI									
	MI									
	SP									
	MD									
	CI									
	RS									
	PU									
	RV									
	MS									
	CB									
	NS									
REFERENCE URBAN	BU									
	SI									
	EB									
	DU									
REFERENCE NONURBAN	CA									
	PM									
	DB									
	SQ									
	SM									
	PS									
No. SUB./CONTAM.										

(Header over columns: SUBSTANCES / CONTAMINANTS; 1. STATIONS 2. TIMES 3. REPLICATES)

Figure 2. Example of Data Evaluation Form.

was made consistent with the Record and Document Management System (Table 1). One of these forms was completed for each study category within each document. The first section of the form identifies the study by author, date, document number, and study type. The second section summarizes the assessment of data quality. Based on the evaluation of study methods and quality assurance/ quality control, a decision concerning the acceptability of the study for the Commencement Bay project data base was made. If the study was unacceptable for the data base, it was not considered further. If the data were acceptable, the information content of the study was summarized in a matrix format, and an assessment of data consistency was conducted. In cases where only part of the data set was acceptable (e.g., detection limits were considered too high for some contaminants but not others), then only the information content of the acceptable data was determined. Reference to the original table number was made, and the acceptable data were identified on a copy of the data table attached to the evaluation form.

During the data review process, care was taken not to evaluate data more than once. Therefore, each data set was traced back to the original author/agency and evaluated based on the information in the original reference. One exception was the sediment contamination data obtained by EPA and WDOE, as summarized by Johnson et al. (1983a-e). These data were evaluated based on information in original references and in Johnson et al. (1983a-e), and the evaluation forms were coded to Johnson et al. (1983a-e). Sediment data collected under the sponsorship of NOAA (Malins et al., 1980, 1982; Riley et al., 1980, 1981) and summarized in Johnson et al. (1983a-e) were coded to the original author.

Data Quality Assessment

Each data set was evaluated in terms of study methods for sample collection, sample handling and storage, QA/QC, analytical determinations, and detection limits. For ecological studies of benthic invertebrates, plankton, and fish, any statistical analyses of "minimum detectable differences" among sampling sites were considered analogous to "detection limits" of a chemical analytical method. Criteria for assessment of data quality were based on EPA guidelines for methods of sample collection, processing,

TABLE 1. DEFINITIONS OF CODES USED ON DATA EVALUATION FORM

CODE		DEFINITION
TYPE OF STUDY	SOURCE/SINK	
Physical Process Studies		
PT	WC	Circulation, Currents
PT	SE	Sediment Transport and Dynamics
Source Studies		
MP	PS	Point Discharges
MP	RS	Runoff Sources
MP	GW	Groundwater Sources
MP	AT	Atmospheric Sources
Contamination and Effects Studies		
MP	SE	Sediment Quality
MP	WC	Water Quality
BA	BI	Bioaccumulation
PA	BI	Pathology
PO	BF	Fish Ecology
PO	BN	Benthic Invertebrate Ecology
PO	BP	Phytoplankton Ecology
PO	BZ	Zooplankton Ecology
BT	WC	Bioassay - Water Column
BT	SE	Bioassay - Sediment

AREA

HY	Hylebos Waterway
BL	Blair Waterway
SI	Sitcum Waterway
MI	Milwaukee Waterway
SP	St. Paul Waterway
MD	Middle Waterway
CI	City Waterway
RS	Ruston Shore
PU	Puyallup River
RU	Ruston-Narrows
MS	Marine Shore
CB	Commencement Bay (>60 ft deep)
NS	Nearshore (general project area)

TABLE 1. (Continued)

CA	Case Inlet
PM	Port Madison
DB	Dabob Bay
SQ	Sequim Bay
SM	Samish Bay
DI	Discovery Bay
ST	Strait of Juan de Fuca
PS	Puget Sound and Hood Canal

SUBSTANCE/CONTAMINANT GROUP

CP	Conventional Pollutants (e.g., Suspended Solids, Nutrients, Oil and Grease, Sulfide)	
ME	Metals	
VO	Volatile Organic Compounds	
BN	Base Neutral Organic Compounds	
AE	Acid Extractable Organic Compounds	
PC	PCBs	
PE	Pesticides	
WQ	General Parameters defined below[a]	
	WQ-Water Quality Study	Ancillary water parameters (e.g., pH, temperature, salinity, DO)
	WQ-Sediment Quality Study	Ancillary sediment parameters (e.g., percent silt/sand/clay; organic C content; volatile solids)
	WQ-Biological Studies	Biological parameters (e.g., abundance, prevalence of liver lesions, species richness)

DATA SOURCE REFERENCES

T	Table[b]
F	Figure[b]

[a] See individual evaluation forms for definition of WQ column for a specific study.

[b] References to tables or figures in original document were made at top of respective substance/contaminant column.

and analysis (U.S. EPA 1979a, b; 1981; also see Tetra Tech 1983 Commencement Bay Quality Assurance Program Plan).

For each method category (sample collection, handling/storage, etc.) limitations of the technique or procedure were noted on the evaluation form. Rejection of data was based on consideration of method limitations and the following criteria: 1) if one or more method categories was considered inadequate, the data were rejected; 2) if two or more method categories were scored as "no description (N)," the data were rejected, except in the case of ecological studies where three or more entries of "no description" was the criteria for rejection. The latter procedure was warranted because such studies seldom give details of QA/QC and "detection limits."

Numerous criteria were employed in evaluation of bioassays. These were primarily concerned with appropriateness, methodology, and performance of bioassays conducted to date. Major criteria were:

- Ecological significance
- Scientific and legal defensibility
- Available routine methodology
- Predictive utility
- General applicability to a wide range of chemicals
- Simplicity and cost
- Degree of simulation of natural conditions
- Flexibility of exposure conditions
- Survival of control organisms
- Comparability with previous bioassay data
- Interpretability of end response.

Details of methods used in evaluating bioassays are given in the Decision Criteria Report.

Sampling Intensity Matrix

For each data set considered acceptable for the data base, a matrix of sampling intensity (number of stations, number of times sampled, and number of replicates) was compiled by area and by substance/contaminant group (Figure 2). In addition, the number of individual parameters measured within a substance/contaminant group was entered at the bottom of each column (e.g., under column ME, the number of metal elements analyzed by a particular investigator was scored). Note that the number of replicates refers to the number of replicate samples, not replicate analyses of contaminant (or conventional pollutant) concentrations. For studies of bioaccumulation and pathology, different biotic groups were pooled. Thus, analyses of fishes and benthic macroinvertebrates were not summarized separately.

For water quality studies only one sampling depth per sampling site was scored in the matrix as a station. Samples taken at various depths in the water column were not tabulated. This procedure was necessary, because the number of sampling depths was often inconsistent among sites. Since only the two-dimensional (areal) distribution of sampling points was summarized, the total information content of most water quality studies is therefore underestimated. Nevertheless, the areal coverage of a study was considered of primary interest, because the Commencement Bay waterways are shallow and areal distribution of sampling sites is a main concern in the study design phase.

All information tabulated in the sampling intensity matrix was entered in a computer file organized by study type. Each line of the file represents a row of the matrix, which is identified by area (Hylebos Waterway, Blair Waterway, etc.) and document number. The total number of samples for a given contaminant group in a given area was calculated as the product of the number of stations and the number of times and the number of replicate samples. Where the number of replicates was inconsistent among sampling sites, the total number of samples was tabled on the original form and entered directly into the computer file. Summary tables were then produced for each study type.

Evaluation of Data Consistency

Based on the sampling intensity matrix and a review of data contained in the original reference, each study was evaluated for data consistency

(Figure 2). High consistency in spatial coverage was defined as sampling of all stations during each sampling time. High consistency in temporal coverage was defined as maintenance of a regular sampling frequency, e.g., weekly, monthly, annually. High consistency in contaminant coverage was defined as analysis of all contaminant compounds in each sample. If sampling was conducted only once, then assessment of spatial and temporal consistency was considered "not applicable (NA)." For biological studies, data consistency was also evaluated for species coverage and parameter coverage (analogous to contaminant coverage in chemical studies).

Station Location Maps

The locations of sampling stations used by previous investigators were plotted on maps of project subareas at a scale of 1:6,000. For data summarized by Johnson et al. (1983a-e), stations locations were taken from a map supplied by WDOE. Station locations of other studies were determined from the best information supplied by the original author. In some cases, this consisted of latitude and longitude coordinates for each station. In other cases, only a rough original map of station locations was available. All station locations should be verified before data is entered into the data base.

DATA EVALUATION RESULTS

The results of the data summarization and evaluation are discussed in the following sections, which are organized according to study categories. The complete results and raw data are contained in the Appendices. Appendix A is a list of documents in the Commencment Bay Project library. Appendix B is a summary of study types found within each document, including evaluations of methods and recommendations for inclusion in the data base. Appendix C is a summary listing of the sampling intensity matrix data, organized by study category.

Physical Processes

Introduction--

The waterways of the Commencement Bay industrial area receive substantial waste loading from point sources, stormwater runoff, groundwater inflow, and atmospheric fallout. Part of the pollutant load is eventually sequestered in waterway sediments. Circulation processes provide a means of redistribution of dissolved and particulate pollutants among waterways or out of the system and into Commencment Bay. Available data on circulation and waterway characteristics that affect pollutant distribution are described in this section.

Waterway Circulation--

Investigations performed by Northwest Consultant Oceanographers, Inc. (Loehr et al., 1981) are the only known detailed studies of circulation within the waterways. The waterway field program consisted of three separate studies:

- Current following drogues set at various depths were deployed and tracked on August 18 and 19, 1980, to evaluate circulation in Hylebos, Blair, Sitcum, Milwaukee, Middle, and City Waterways during neap tide conditions

- Drogues set at various depths were deployed and tracked on August 27 through 29, 1980, in Hylebos, Blair, Sitcum, Milwaukee, and City Waterways to evaluate circulation during spring tide conditions

- A more detailed study of Blair Waterway was performed in February 17 and 18, 1981, to evaluate the influence of higher Puyallup River discharge (11,000 ft^3/sec in February vs. 2,000 ft^3/sec in August) on circulation. Drogue studies were performed along with measurement of current velocities and temperature, salinity, and depth profiles.

The results of the studies indicate very complex circulation patterns within the waterways. Velocity profiles inferred from the movement of drogues varied vertically and with respect to position in the outer, middle, or inner portion of an individual waterway. In general a net inflow of Commencement Bay water was observed in a surface layer [to 0.5 m (1.6 ft)] and in a bottom layer below 6 m (20 ft). Net outflow was observed in a layer from 2 to 6 m (7 to 20 ft).

Surface layer flow was strongly influenced by winds. Winds from the south or southeast could reverse the direction of the surface layer during flood tides. The upper 1 to 2 m (3 to 7 ft) of the waterway is replaced by surface water from Commencement Bay during large flood tides if not opposed by winds.

Water velocities inferred from drogue measurements were highest in near surface waters. Maximum surface velocities ranged between 7 and 30 cm/sec and were highest in the longer waterways. Bottom velocities inferred from drogues set from 1 to 3 m (3 to 10 ft) above the bottom ranged from 3 to 7 cm/sec. Maximum current velocities measured by current meter in Blair Waterway reached 21 cm/sec near the surface and were generally about 8 cm/sec near the bottom but reached peaks near 17 cm/sec. Both the current meter and drogue observations indicated some cross-channel flow. Drogues frequently traveled a meandering path and indicated the presence of eddies.

The plume of the Puyallup River generally influences the surface waters of the waterways with the exception of City Waterway. The plume usually does not reach the southern portion of Commencement Bay, so the surface waters of City Waterway are generally more saline and less turbid than the surface waters of the other waterways. The problem of transfer of water or pollutants from one waterway to another was not addressed in the Loehr et al. (1981) report.

Waterway Mixing--

The circulation of waterways is unique in that the source of fresh water is at the mouth (with the exception of Hylebos), rather than the head of each waterway. Mixing is primarily driven by the tide (Loehr et al., 1981) which has a diurnal range of 3.6 m (11.8 ft). Circulation of the surface layer can be modified by the wind.

The discharge of the Puyallup River influences the surface layer of Commencement Bay which in turn is the source of the surface water entering the waterways (with the general exception of City Waterway). Density profiles measured in Blair Waterway (Loehr et al., 1981) indicated the depth of the pycnocline to be about 3 m (10 ft). Most of the direct influence of Puyallup River water is therefore in the upper 3 m (10 ft) of the water column.

Flushing rates (or residence times) were estimated for each waterway by Loehr et al. (1981) using two methods. The first method assumes that the "new" water brought in by each flood tide completely replaces an equivalent volume of "old" water in the basin without mixing. The residence time or flushing rate is thus the number of tidal cycles or calendar days required to completely replace all of the "old" water. The method is expressed as:

$$t = \frac{(x)(V_L)}{V_H - V_L}$$

where:

t = flushing time, tidal days

x = fraction of original basin water to be replaced

V_L = waterway volume at mean lower low water

V_H = waterway volume at mean higher high water.

The second method used by Loehr et al. (1981) is similar but assumes that 100 percent mixing occurs between the "new" and the "old" water on each tidal cycle so that the volume of "old" water replaced is less than the volume of new water. This method is expressed as:

$$t = \frac{l_N Z}{l_N (V_L / V_H)}$$

where:

Z = fraction of original basin water remaining in the basin after time.

In both methods, it is assumed that there is no recirculation so that no "old" water is present in the "new" water entering the waterway.

Actual flushing times of the waterways are probably somewhere between the values estimated by the two methods as presented in Table 2. Actual flushing times will also vary because of factors not included in the "first-order" flushing rate estimation methods. For example, tidal ranges other than 3.6 m (11.8 ft), strong winds, density differences, and precipitation effects will cause some change in the flushing rate. Nevertheless, the flushing rate values and tidal prism volumes presented in Table 2 provide a means of comparing the flushing characteristics of one waterway to another. No direct observations of dispersion rates or flushing and residence times are known to have been made in the waterways.

Commencement Bay Circulation--

The configuration of the Commencement Bay basin greatly influences the circulation within the bay. The significant features of the basin are: the long southwest shore which extends north of the northeast shore, the absence of a sill between the East Passage and the bay, the gradual decrease of water depths in the interior of the bay, and the existence of a sill between East Passage and the Narrows. These features facilitate the natural diversion and flow of deep East Passage water into Commencement Bay.

The circulation patterns within the bay are the result of the complex interaction of the tide, the Puyallup River discharge, and the wind. Circulation studies of the bay have primarily employed drogues with supplemental information being obtained from the Puget Sound hydraulic tidal model, aerial photographs, and current profiles. These short-term observations have recently been augmented by results of two long-term (60-day) deployments

TABLE 2. COMPARISON OF WATERWAY FLUSHING CHARACTERISTICS

	Tidal Prism Volume as Percentage of Waterway Volume	Flushing Rate[a] (No Mixing)	Flushing Rate[a] (Complete Mixing)
City Waterway	59	1.8	10.3
Middle Waterway	208	0.5	4.2
Milwaukee Waterway	35	3.0	16.1
Sitcum Waterway	35	3.0	15.9
Blair Waterway	38	2.7	14.8
Hylebos Waterway	69	1.5	9.1

[a] In calendar days.

Data from Loehr et al. (1981).

of current meters within the bay (Cannon and Grigsby 1982). The data collection also included measurements of temperature, salinity, and light transmission (Baker and Walker 1982).

Brown and Caldwell (1957) studied circulation of Commencement Bay through deployment of drogues, evaluation of aerial photographs, physical model tests, and measurement of salinity. Drogues were set at 3 m (10 ft) and 30 m (100 ft) along the Ruston Shoreline. The shallow drogues drifted in a counterclockwise pattern moving southeast along the shoreline, offshore during ebb tide, and northwesterly during flood tide (Figure 3). The deeper drogues moved alongshore in a similar pattern but moved progessively onshore rather than offshore.

Aerial photographs presented in the Brown and Caldwell (1957) report show turbid Puyallup River water moving out of Commencement Bay on ebb tide against the north shore and around Dash Point. The sequence of photographs also illustrated the effect of winds from the north on the plume's position where the plume is held against the Ruston Shoreline. Tests in the University of Washington physical model and field observation of surface salinity distribution also indicated a counterclockwise circulation pattern in the near surface waters of Commencement Bay.

Two quiescent areas were identified from the surface current studies. The largest area was the northeast corner of Commencement Bay at the mouth of Hylebos Waterway and extending into the waterway. The second area included City Waterway and the area near its mouth.

A generalized description of the deep water circulation was also provided. During flood tides, deep water flows southward in East Passage. As the flow encounters the Tacoma shoreline, the flow splits and establishes an alongshore current into Commencement Bay, setting up the counterclockwise rotation. An upwelling of deep water is also established along the Tacoma shoreline. While the report states that the deep circulation is generally counterclockwise, two sets of observations of drogues set at 61 m (200 ft) exhibited a clockwise movement.

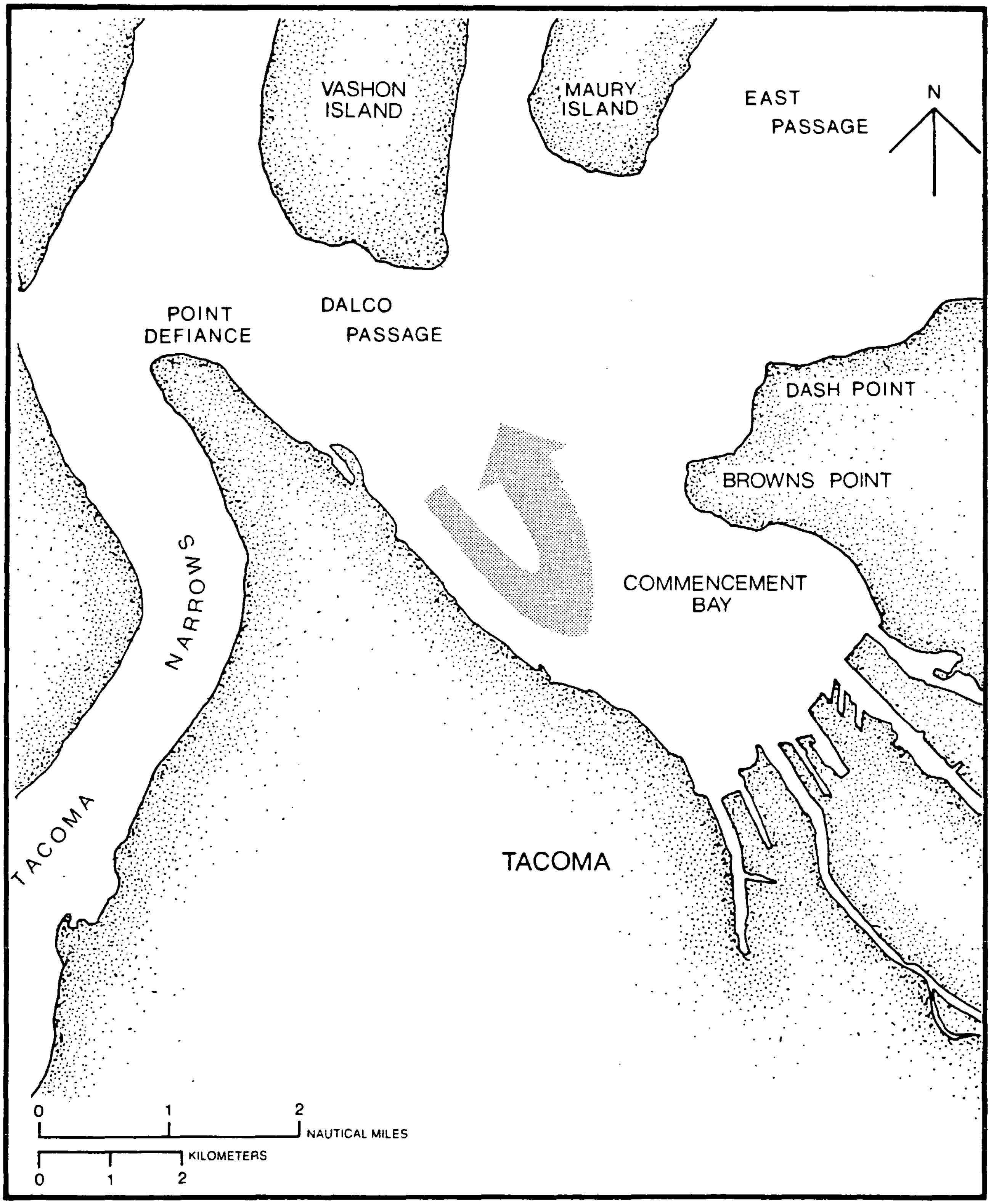


Figure 3. Generalized trajectories of five current drogues set at 3 m (10 ft) over an 8 hour period on July 9, 1956. (Brown and Caldwell 1957).

Drogue studies were performed by the City of Tacoma (1979) in Commencement Bay with the launching point located near the mouth of the Puyallup River. Surface drogues were observed to reach Browns Point and did not return on the flood tide (Figure 4). The surface current was relatively shallow and seldom exceeded 1 foot in depth. The current drogue observations at all depths (1, 5, 20, and 35 m) generally complemented the results of Brown and Caldwell (1957).

Loehr et al. (1981) conducted drogue studies in Commencement Bay in September, 1980, and February, 1981, to assess nearshore circulation patterns during average tidal conditions and for periods of low and high Puyallup River discharge. These data provide the widest spacial representation of the circulation patterns within Commencement Bay. Unfortunately, however, wind conditions during the study period were not recorded.

The observed drogue trajectories are displayed in Figures 5 and 6. Note that each set of trajectories does not represent simultaneous observations. Observations for similar tidal stages over the study periods have been combined.

The drogue data of Loehr et al. (1981) do not support the previous generalization of Commencment Bay circulation as a counterclockwise motion with the exception of the flow at 20 m during September, 1980. Instead, the flow is variable and suggests a clockwise circulation pattern in the top 10 m on both flood and ebb tide. It must be noted again, however, that wind conditions were not specified for any of the previous drogue studies.

Cannon and Grigsby (1982) have reported preliminary results of data collected from two moored current meter arrays in Commencement Bay. The locations of the two arrays, designated CB-3 and CB-4, are shown in Figure 7. The CB-3 record extended from 9 September 1980 through 11 December 1980 (64 days) with current meters at depths of 24 m and 74 m. The record for CB-4 covered the same period in 1980 with current meters set at 25 m, 75 m,

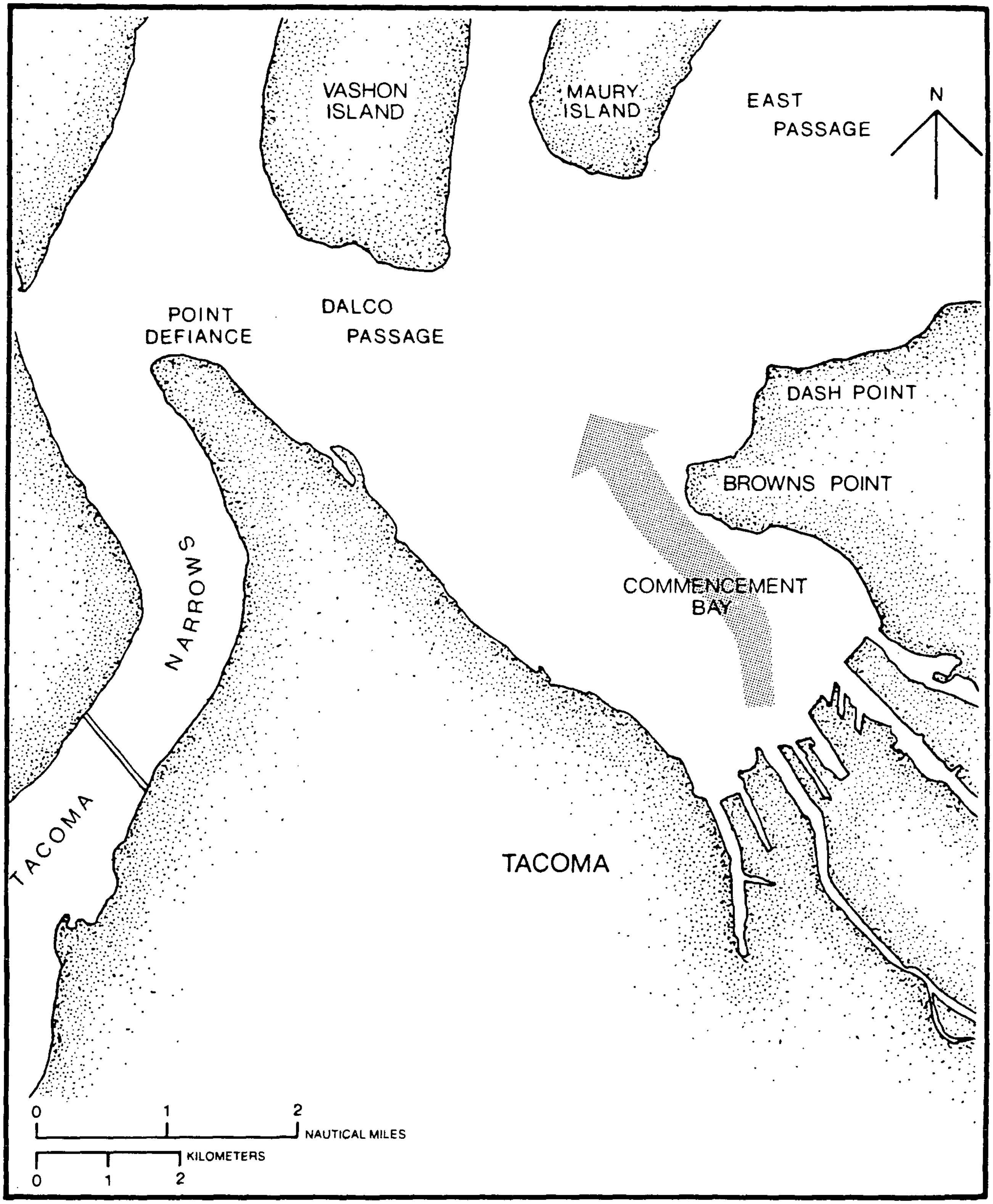


Figure 4. Generalized trajectory of three current drogues set at 1 m over a 4.5 hour period (flood tide) on July 30, 1979. (City of Tacoma, 1979).

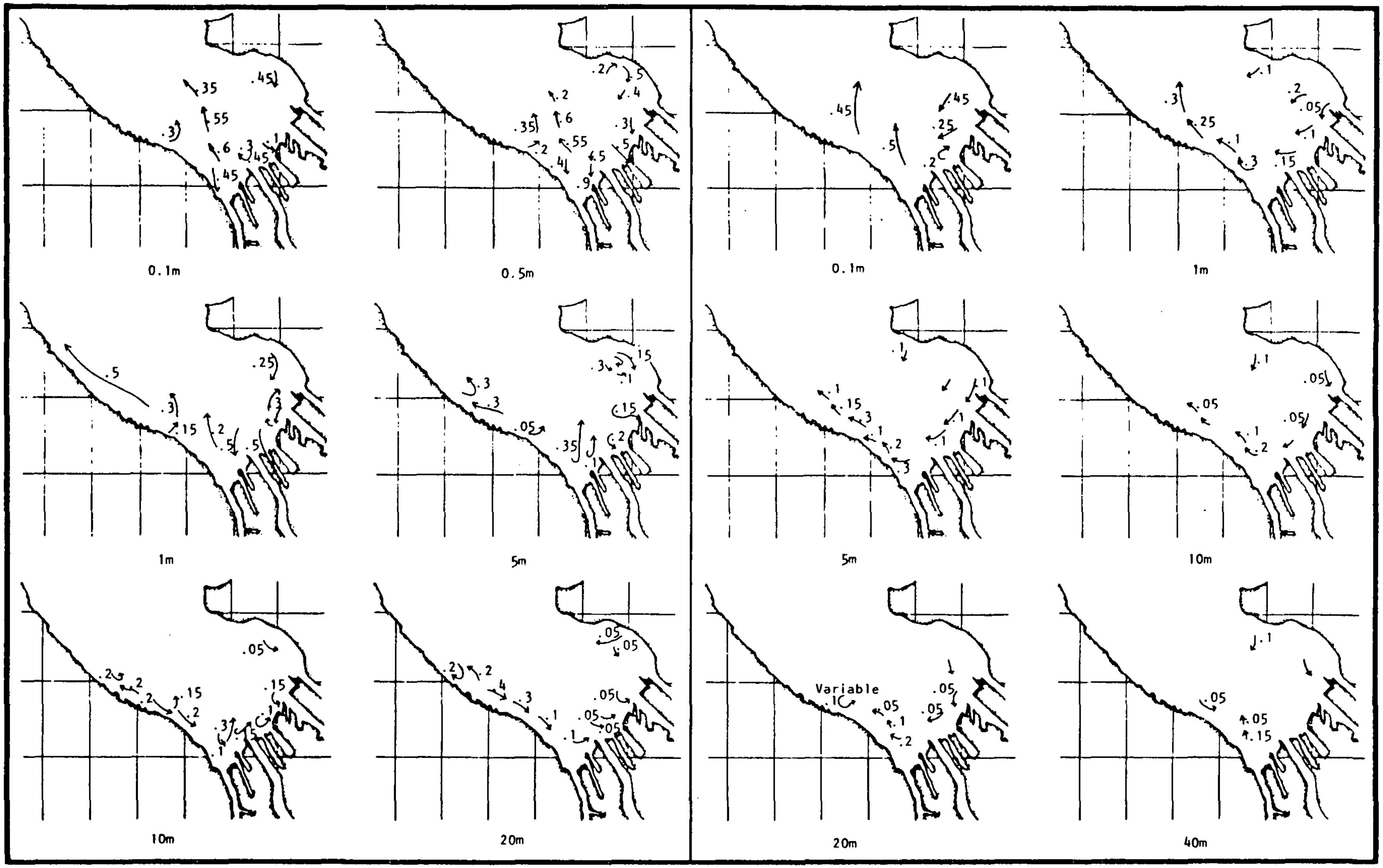


Figure 5. Trajectories of drogues set at specified depths during a flood tide on 9-10 September 1980 (left panel) and 9-12 February 1981 (right panel). The numbers indicate speed in knots. (Loehr et al. 1981).

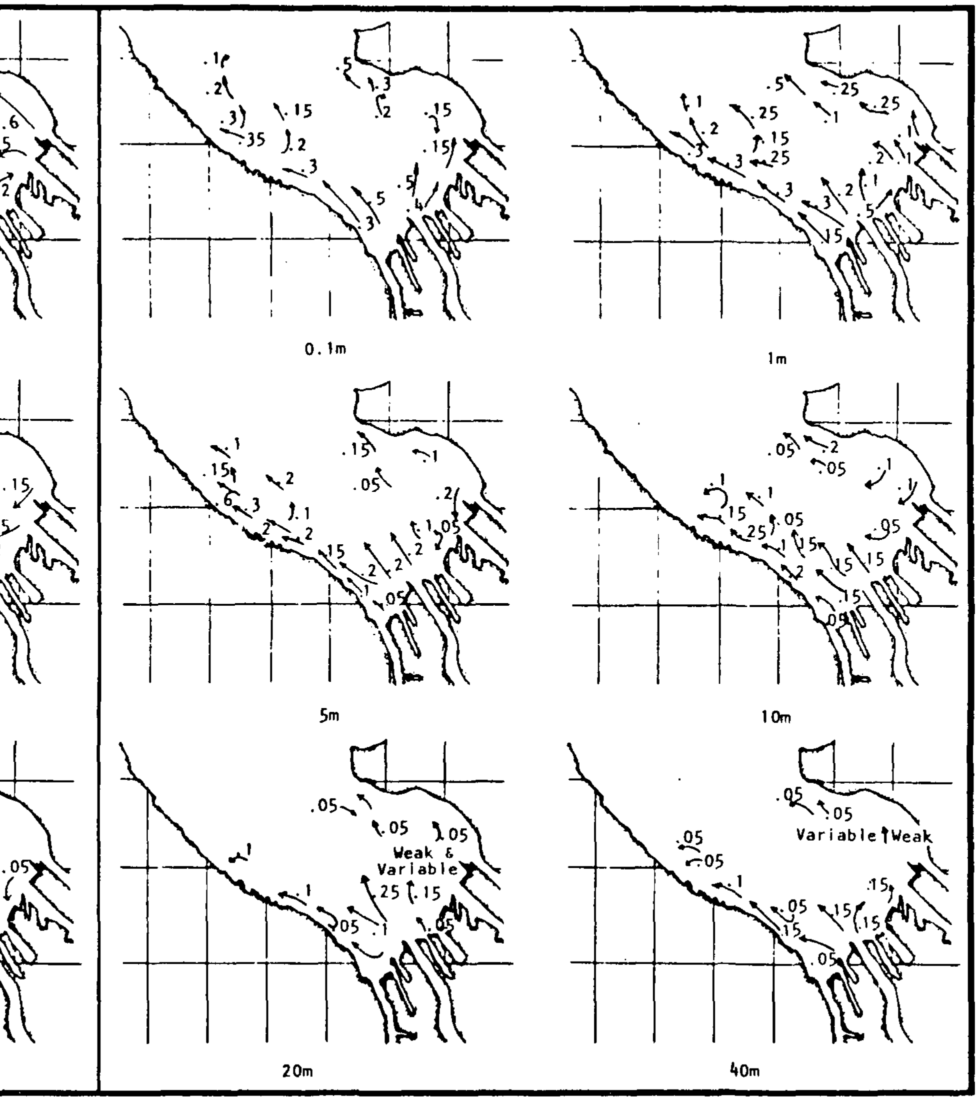


Figure 6. Trajectories of drogues set at specified depths during an ebb tide on 9-10 September 1980 (left panel) and 9-12 February 1981 (right panel). The numbers indicate speed in knots (Loehr et al. 1981).

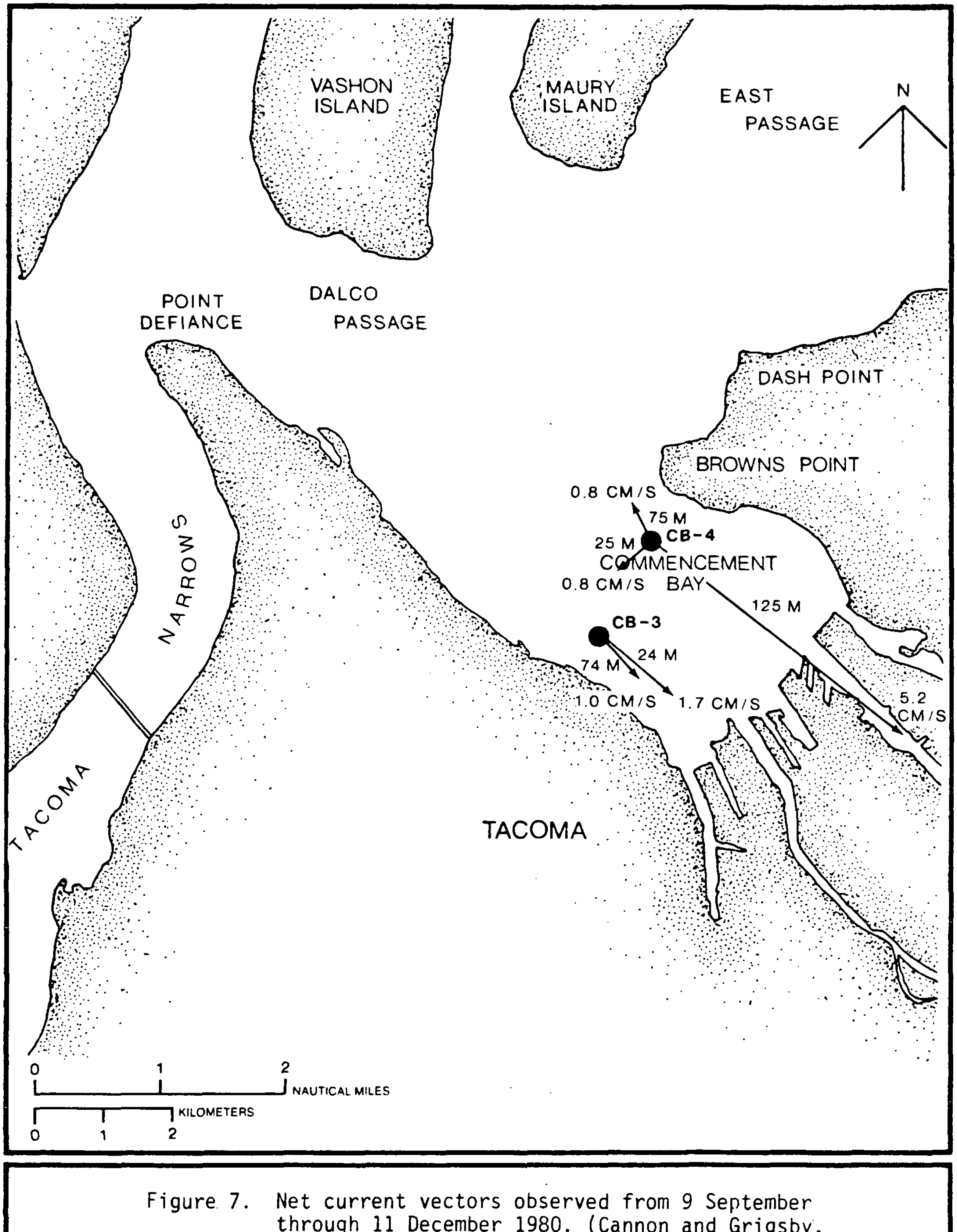


Figure 7. Net current vectors observed from 9 September through 11 December 1980. (Cannon and Grigsby, 1982).

and 125 m. Data were also collected at CB-4 for the period 24 March through 3 June 1981 (71 days) with current meters recording at 27 m and 127 m.

The 1980 data (Cannon and Grigsby 1982) are summarized in Figure 7. The net current vectors indicate the presence of a net counterclockwise circulation at 25 m and 75 m. A strong counterflow at 125 m appears to be present. This same counterflow at 125 m appears in the 1981 data (Figure 8) but at much lower speed.

Baker and Walker (1982) have presented data on salinity distribution, light attenuation (suspended solids), and current data for the same period as Cannon and Grigsby (1982). It should be noted that significant discrepancies exist in the net current vectors reported for the same data sets from Stations CB-3 and CB-4. Since both reports are preliminary in nature, it is expected that the differences will be reconciled in future reports. The values of Cannon and Grigsby (1982) have been presented above because they appear to be the more reasonable values. The accuracy of the data has not been verified, however.

The salinity and light attenuation data presented by Baker and Walker (1982) provided additional evidence of the circulation pattern in Commencement Bay. These data indicate a counterclockwise circulation pattern of the surface waters. In addition to the surface turbidity plume which originates from the Puyallup River, Baker and Walker (1982) observed a mid-depth turbidity plume extending outward from the head of the bay at a depth of 5 m to 70 m. This feature, which was often thicker and more turbid than the surface plume, thus represents a significant particle distribution process in the bay. Baker and Walker (1982) suggest that the source of the particles is resuspension of shallow sediments at the head of the bay by tidal currents. A third turbid layer along the bottom of Commencement Bay was also attributed to resuspension of bay bottom sediments.

In summary, circulation in Commencement Bay has been shown to be variable, both laterally and vertically. A generally counterclockwise flow pattern is present in the surface waters which may extend downward to 75 m. The Puyallup River plume, which occurs in the upper 1 to 2 m of the water column,

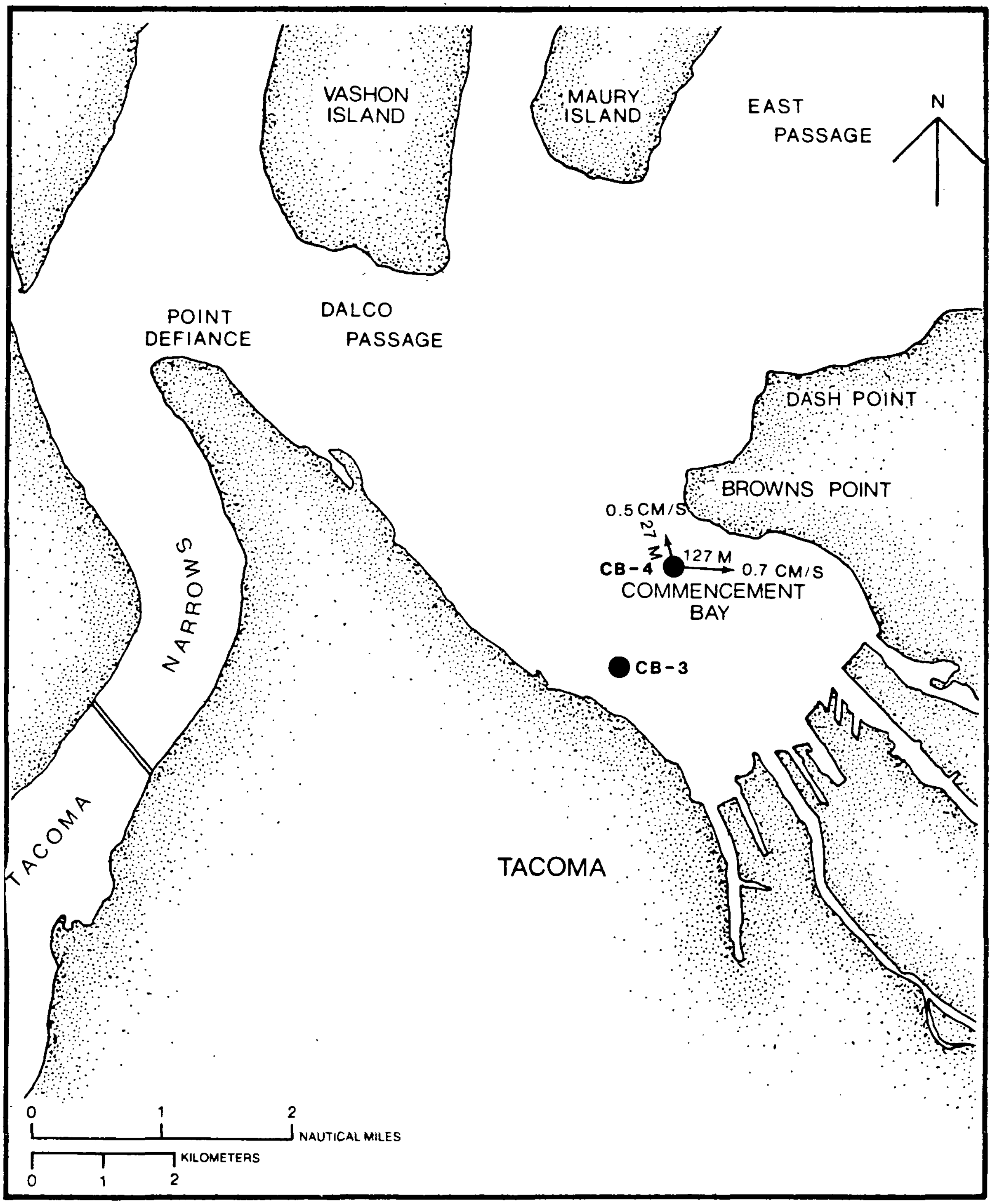


Figure 8. Net current vectors observed from 24 March 1981 through 3 June 1981. (Cannon and Grigsby, 1982).

generally moves out of the bay along the north shore. The plume responds to wind forcing, however, and can be directed along the south shore by winds from the north. Wind data for 1979 collected by the Puget Sound Air Pollution Control Agency (1980) from stations in Tacoma and Maury Island suggest that winds from the northern quadrants occur approximately 30 percent of the time.

Data presented by Baker and Walker (1982) indicate two additional modes of transport for suspended particles. Tidal currents at the bottom of Commencement Bay appear to be capable of resuspending sediments and producing a bottom nepheloid layer which is transported with the bottom circulation. A mid-depth plume is also present at a depth of 50 m to 70 m which, according to Baker and Walker (1982), may originate from resuspension of bottom sediments in the shallower, southeastern portion of Commencement Bay. There is no evidence that the particles in the mid-depth plume originate in the waterways.

Contaminant Sources

For the purposes of this study, contaminant sources were separated into four categories. Point sources consist of all waterborne effluent emissions; all point sources have NPDES permits. Although some industries have NPDES permits for storm water runoff, these sources have been placed in the second category, runoff and stream sources. This category includes all of the streams, seeps, ditches, and drains discharging to the study subareas, including those ditches and drains receiving effluents from more than one permitted industry. This division is somewhat arbitrary, but serves to separate industrial effluent contaminant loadings from those originating from runoff, unknown, or unspecified sources. The third category includes contaminant inputs from spills which have occurred within the study area. The fourth category, groundwater sources, encompasses all subsurface contaminant transport that eventually reaches the study subareas. The final category, atmospheric sources, consists of all airborne toxic pollutants entering the waterways directly, that is, those substances deposited to the water surface from the atmosphere. Atmospheric pollutants deposited to land surfaces and subsequently carried to the waterways by storm runoff are included in the runoff sources category.

The identified waterborne contaminant sources with acceptable data are shown in Table 3. Most of the sources with acceptable data are contributors to Hylebos and Blair Waterways, and 85 percent are in three waterways: Hylebos, Blair, and City.

Data compilation and evaluation procedures have been discussed previously (see above, Data Evaluation Procedure). In general, the evaluation of contaminant source data followed these procedures. Source data were rejected if any of the method categories were considered inadequate, or if more than two of the method categories were not described. Although some WDOE studies did not contain documentation on some or all of the method categories, they were accepted after contacting WDOE and verifying that standard procedures were employed.

Contaminant source sampling presents unique problems in sample collection. Methylene chloride was occasionally used as a bottle rinse and a residue was detected in later analyses. Grab samples yield information on contaminants present at one point in time, so samples may be manually composited to obtain a better characterization of an effluent over a longer time period. Automatic composite samplers vary in reliability, and care must be taken to ensure that the equipment is free of extraneous contaminants that could bias laboratory analyses. The precision and accuracy of flow measurements vary, and in some cases flows have been estimated. Where estimated flows are used to compute mass loadings, the uncertainty introduced by estimation should be recognized. Some of the groundwater data reviewed were rejected due to inadequate or undescribed sampling technique. Examples of possible inadequacies are improper well construction, inadequate sampling methods, failure to use uncontaminated tubing in drawing the samples, and failure to pump wells prior to sample collection.

Very little toxic contaminant source data in the study area is the result of ongoing regular monitoring programs. Nearly all of the data are products of one-time or infrequent surveys. Therefore, in evaluating

TABLE 3. SPATIAL DISTRIBUTION OF CONTAMINANT SOURCES WITH ACCEPTABLE DATA

Subarea	Runoff Sources: Point Sources	Runoff Sources: Drains	Runoff Sources: Seeps	Groundwater Sources	Sources per Subarea	Percent of Total
Hylebos	8	31	9	2	50	43
Blair	2	26	4		32	28
Sitcum		2			2	2
Milwaukee					0	0
Puyallup	1	3			4	3
St. Paul	2	2			4	3
Middle		1			1	1
City		15		1	16	14
Ruston Shoreline	4	2			6	5
Total	17	82	13	3	115	

specific studies, neither spatial nor temporal consistency are applicable. The studies were designed to accomplish certain objectives (e.g., to characterize flow and contaminant concentrations at a given point during a chosen time period), and are not directed toward providing a time series of data for a set of sampling stations. Few of the studies considered can be evaluated in terms of spatial and temporal consistency, therefore, no discussion of temporal and spatial consistency of individual studies is presented here. Instead, the data are aggregated by study subarea, and the spatial and temporal consistency of the acceptable studies is discussed for each subarea as a whole.

A summary of the available point source, runoff source, and groundwater source data is presented in Table 4. Over 100 documents were initially screened and, of these, 67 studies were evaluated (note that some documents contained studies in more than one medium, such as both runoff and point sources). Few point and runoff source documents were rejected, but a high proportion of the groundwater studies were. This was due primarily to improper well construction, inadequate sampling techniques, or a failure to document sample collection, storage, handling, and preservation procedures. Few data sources on atmospheric and contaminant inputs from spills exist, so these sources have not been presented in Table 4 and will be discussed later.

In the data base compilation, studies were partitioned by waterway, with a line of data entered for each waterway within each study (e.g., see Appendix C). Since some of the runoff studies covered multiple waterways, the total number of data entry lines (30) exceeds the number of studies (21). Six contaminant groups were scored for a given line, each contaminant group having three items (stations, times, and replicates). Therefore, the total number of items in a given line is 18. The product of this total with the number of lines equals the upper limit of information in the contaminant source data base. The number of data lines, entries, and their products are displayed in the last three columns of Table 4.

TABLE 4. SUMMARY OF AVAILABLE INFORMATION FOR STUDIES ON CONTAMINANT SOURCES

Medium	No. Available Studies			Data Base		
	Accept[a]	Reject[a]	Total	No. Studies/ Areas[b]	No. Items[c]	Product
Point Sources	23	5	28	23	18	414
Runoff Sources	21	4	25	30	18	540
Groundwater	7	7	143	7	18	126
Total	51	16	67	60	--	1,080

[a] Accept and reject indicate total numbers of studies accepted or rejected for the Commencement Bay data base.

[b] No. studies and areas within studies considered acceptable for data base. This number equals the total number of rows with information in the sampling intensity matrix, or the number of lines in the computer summary file for each study type (see Appendix C).

[c] No. items is the number of individual cells within a row of the sampling intensity matrix. For example, six columns were relevant to point source studies. Since three items (No. stations, No. times, No. samples) were scored per column, a total of 18 items of information were collected for each matrix row.

Point and Runoff Source Data--

In the following discussion point and runoff sources are considered together since many of the study documents include data on both sources. The principal sponsors of point and runoff source studies are the public health and environmental protection agencies with jurisdiction over the Commencement Bay area. WDOE and EPA collaborate to select industries for Class II surveys, which are subsequently performed by the two agencies and reported by WDOE. WDOE Class II inspections have usually been conducted in conjunction with receiving environment surveys which focus on contaminant levels in the receiving waters and sediments. A Class II inspection involves a tour of the targeted industrial facility, measurement of the effluent flows, and sampling of the effluent. Since 1975 eight industrial and municipal facilities in five subareas have been surveyed. They are Pennwalt Corporation, Sound Refining Company, and Occidental (formerly Hooker) Chemical in Hylebos Waterway; Reichold Chemical and U.S. Oil and Refining in the Blair watershed; St. Regis Paper Company at the head of the St. Paul Waterway; the Tacoma Central sewage treatment plant on the Puyallup River; and the ASARCO copper smelter along the Ruston Shoreline.

During the Class II inspections effluent flow was measured by flumes, weirs, stream gages, or water meter readings, and the most reliable measurement used in mass loading calculations. Flows from drains and seeps were measured by timing flow into a bucket. This method worked well for discharges that could be routed to one diversion point, but where they could not a portion of the flow was measured and the total estimated. Estimation of flows is indicated in data summaries presented in this report.

Pollutant samples were collected by grab sampling and with two ISCO automatic composite samplers set to collect effluent over a 24-h period. Upon collection, samples were chilled on ice in coolers until analyzed. Analysis of metals was carried out by the WDOE laboratory in Tumwater, WA, with the exception of mercury, which was tested at the WDOE laboratory in Redmond, WA. Priority pollutant analyses were done by EPA or EPA contract laboratories. Results of organic pollutant analyses were generally reviewed by Joseph Blazevich, EPA Region X, at the EPA Manchester laboratory for adequacy of quality assurance procedures.

Class II surveys provide highly acceptable data on point sources to Commencement Bay waters. The WDOE personnel are experienced in sampling and the procedures employed are amply documented. The surveys contain maps showing precise locations of the sampling stations, with the dates and times of sampling indicated. A major limitation of these surveys is the restriction of the subject facilities to the major discharges; consequently, minor discharges have not been surveyed in such depth.

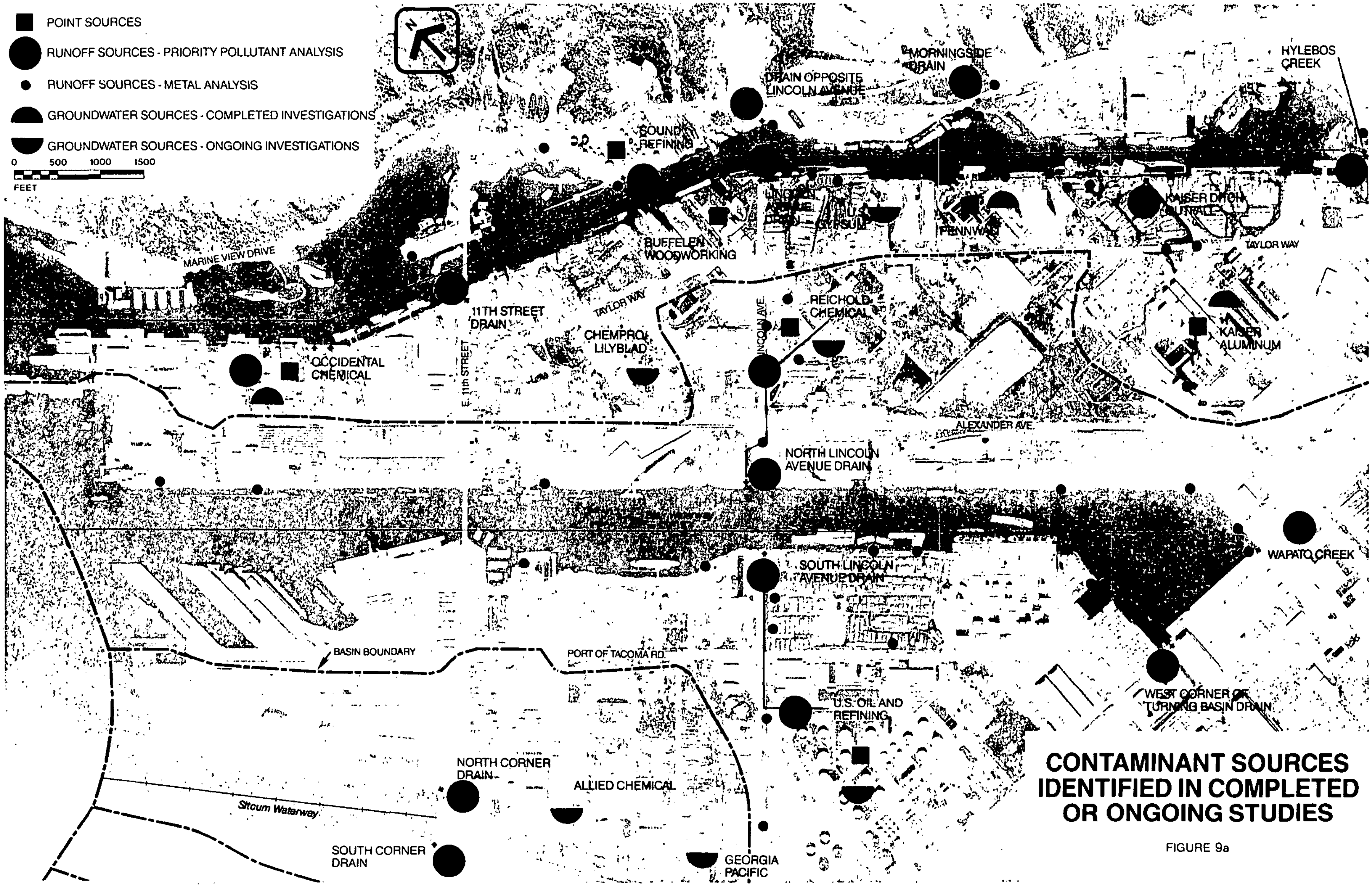
WDOE receiving environment surveys have as primary objectives the quantification of pollutant concentrations in the receiving waters and determination of toxic effects on marine organisms (Johnson and Prescott 1982d). In 1982, surveys were conducted at the following sites: Reichold Chemical, Sound Refining, U.S. Oil and Refining, St. Regis Paper Company, Pennwalt Corporation, and the Tacoma Central sewage treatment plant. Previous reports have been evaluated and included in the contaminant source data base, but these six reports comprise the most recent WDOE evaluations of the effects of the targeted facilities on water quality and biota. Some pollutant source data are included in those reports, and the data quality compares to that of the Class II surveys. Sample collection, handling, and storage procedures were identical to those of the Class II surveys, or, where different, the differences were properly documented.

The most comprehensive data source consists of the series of five reports prepared by Johnson et al. (1983a-e), each one compiling and summarizing data on a waterway, or, in the case of the fifth report, three waterways, the Puyallup River, and the Ruston Shoreline. Since data from this series were gathered from a variety of sources, the original documents were obtained and the data evaluated for adequacy of sampling collection, handling, storage, and analysis. Much of the non-WDOE data came from two EPA investigations (U.S. EPA 1980a, b).

Two EPA investigations were conducted in 1980 to provide information for planning subsequent surveys (U.S. EPA 1980a, b). All of the collected samples were grab samples (no composite sampling). Sample collection, handling, and storage methods are not documented, and "abbreviated laboratory procedures" were used to obtain quick results needed to rapidly identify sites with potential for additional study. The station locations are not precisely described due to the small scale of the maps and the illegible hand lettering. Nevertheless, in spite of these deficiencies, the EPA data were accepted because of their utility in corroborating data from other studies and indicating areas worthy of future attention. In these studies, as with all other documents reviewed, care was taken to ascertain whether samples were receiving water measurements or analyses of contaminant sources entering the waterways. Since the original reports did not always clearly distinguish samples of the receiving waters near a discharge from those of the discharge itself, a careful inspection of the station location map and the station descriptions was necessary.

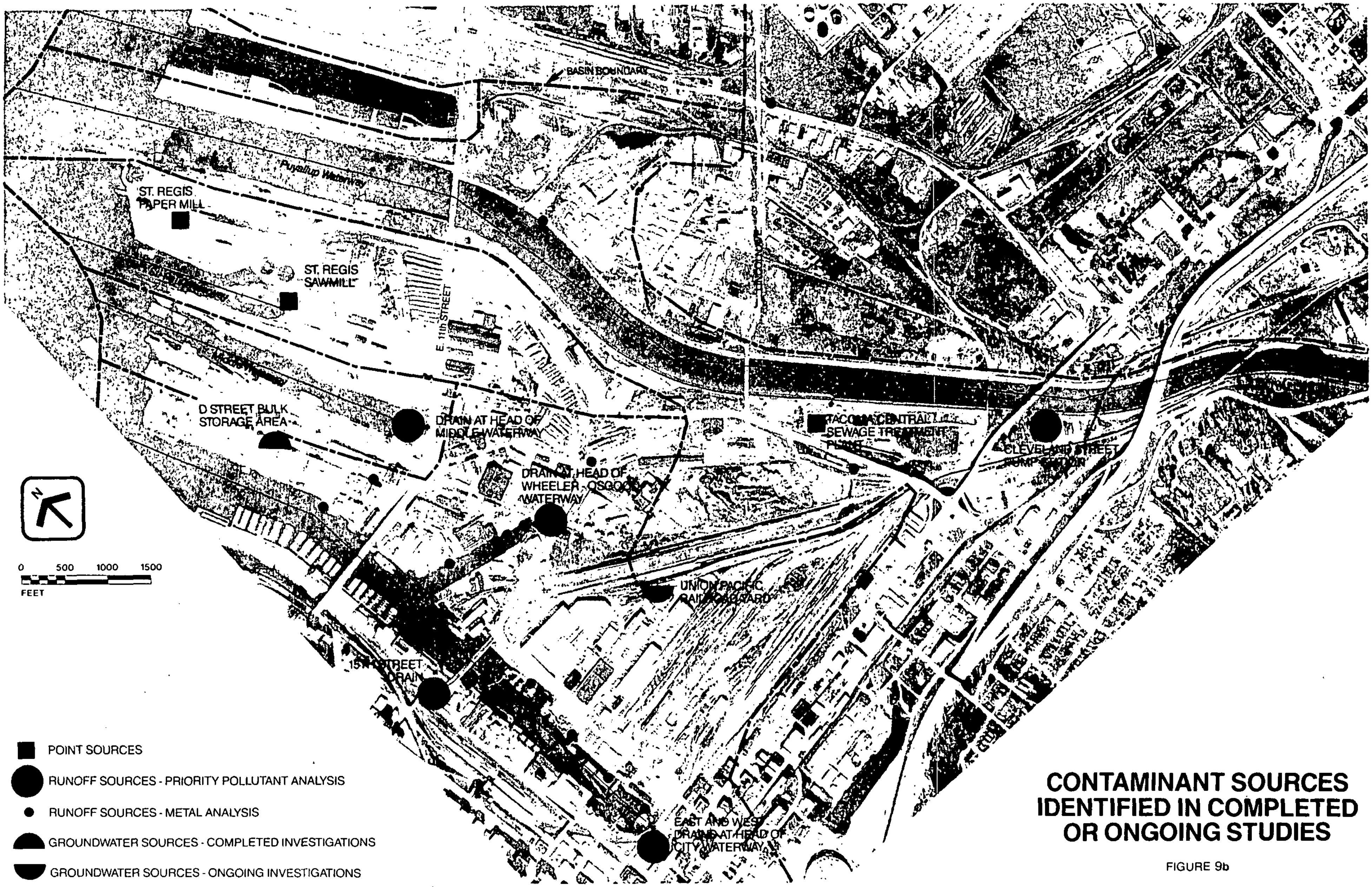
The most extensive survey of contaminant sources to the study subareas is the drainage system investigation sponsored by the Tacoma-Pierce County Health Department (TPCHD) and documented in Rogers et al. (1983). An effort was made to locate, describe, and map every seep, ditch, and drain in the Tacoma nearshore/tideflats area. In addition, samples were collected at 43 sites for analysis of metals, specific conductance, total organic carbon, total organic halogens, and oil and grease. Of these, the metals results were judged to be acceptable for inclusion in the contaminant source data base. Drains, ditches, directions of flow, and outfall points are depicted, and the described points are numbered. The reference system requires the use of a key to link map numbers to report numbers. Some of the map numbers cover as many as 12 distinct outfall pipes, resulting in imprecision in locating a specific pipe. Whenever possible, however, the TPCHD number has been incorporated into the contaminant source data base.

Spatial Coverage of Contaminant Sources--Sampling station locations are shown in the map on Figure 9a,b. Note that in some instances multiple stations have been represented by one symbol, as in the case of the Pennwalt seeps and drains. In all, approximately 112 point and runoff sources were found to have acceptable data. Sources entering Hylebos and Blair have received the most extensive and intensive sampling, with 71 percent of



CONTAMINANT SOURCES IDENTIFIED IN COMPLETED OR ONGOING STUDIES

FIGURE 9a



CONTAMINANT SOURCES IDENTIFIED IN COMPLETED OR ONGOING STUDIES

FIGURE 9b

the total number of stations located in these two waterways. Forty-eight stations were sampled in Hylebos, 32 in Blair, and 15 in City Waterway. The other subareas have few sampled stations: the Ruston Shoreline with 6, the Puyallup River with 4, St. Paul Waterway with 4, Sitcum Waterway with 2, Middle Waterway with 1, and Milwaukee Waterway with none.

One limitation of the existing studies is that there is no widely accepted system of station identification being employed by investigators. Consistent use of a station identification system would facilitate pooling and comparing data from different studies.

In order to compare the relative spatial coverages of point and runoff sources in different subareas, a spatial coverage index was developed. First, the numbers of stations which represented direct contribution of flow to each waterway were found. The direct contribution stipulation was applied since an index of knowledge of the boundary inflows from point and runoff sources was desired. Next, the total numbers of pipes, ditches, drains, and seeps with direct input to each subarea were taken from the map, key, and field work sheets provided by Rogers et al. (1983). A difference was calculated, yielding the total number of uncharacterized discharges for each subarea. Finally, the spatial coverage index is the ratio of the sampled stations to the total number of stations in the waterway (Table 5). Ruston Shoreline and City, Blair, and Hylebos Waterways have the largest numbers of unsampled stations, indicating large data gaps in the spatial coverage of these subareas. St. Paul, a small waterway with only four identified drains, has had good spatial coverage. Even though Hylebos has many unsampled stations, 46 stations have been sampled, resulting in a better-than-average spatial coverage index. All of the other subareas have lower spatial coverage indices. The subareas are ranked in Table 5 in order of descending spatial coverage index. The subareas with the lowest rankings are City, Blair, Milwaukee, and the Ruston Shoreline, indicating a lack of point and runoff source data in these subareas.

The spatial coverage index can be misleading, though, since it gives each discharge equal weight even though the flows and mass loadings of pollutants may vary greatly. A mass loading index was considered, where

TABLE 5. SPATIAL COVERAGE INDEX

Subarea	Stations Sampled[a]	TPCHD Stations[a]	Unsampled Stations	Spatial Coverage Index (%)	Spatial Coverage Ranking
Hylebos	46	122	76	38	2
Blair	18	125	107	14	7
Sitcum	2	8	6	25	5
Milwaukee	0	3	3	0	9
Puyallup	4	16	12	25	4
St. Paul	4	4	0	100	1
Middle	1	4	3	25	3
City	13	76	63	17	6
Ruston Shoreline	6	65[b]	59	9	8
All Subareas	94	423	329	22	

[a] Only stations directly discharging to the subarea are included.

[b] Based on preliminary information obtained from TPCHD (Mitchell, J., 26 Oct 83, personal communication).

the mass loadings of key contaminants would be compared to the total estimated mass loading to each subarea. This idea was abandoned since there is insufficient information on the total mass loadings. Instead, an attempt to develop a flow index was made, where the sampled flow was compared to the total flow entering the waterway. Where discharge rate was unknown, an arbitrary flow of 0.001 MGD was assigned to each discharge point on the TPCHD map (Rogers et al., 1983). Although flow rates of many small drains in the study area are not known, a flow rate of 0.001 MGD was selected as the estimated flow based on the few measured flows in the surface runoff observation file. The resulting flow indices gave high coverage ratings since the sampled flows were much greater in magnitude than the unsampled discharges, which were assumed to be small. For example, City Waterway has 13 sampled sources discharging directly to the waterway. Of these, flows have been measured at four stations for an average total of 13.44 MGD. Since flows for the other nine sampled stations are unknown, a flow of 0.009 MGD (0.001 MGD each) is assumed, for a total sampled flow of 13.449 MGD. The flow from the 63 unsampled stations is assumed to be 0.063 MGD, giving a total waterway input of 13.512 MGD. The flow ratio is 13.449/13.512, or 0.995, a high degree of spatial coverage due to the large flows of the four major drains. Because of the limiting assumptions of the flow index, it has not been displayed in a table here. The exercise points out, however, a major data gap in establishing mass loadings of contaminants: a lack of flow data on most of the ditches, drains, and seeps. Additional flow information would be of great utility in determining a sampling strategy for source identification. In particular, flow measurements during dry and storm periods would provide a basis for selecting stations for additional sampling.

Most of the nine major dischargers have received good sampling coverage in comparison to minor dischargers and runoff sources. ASARCO, Occidental Chemical, Pennwalt, Sound Refining, and the two Tacoma sewage treatment plants have been sampled from three to eight times, with most of the analyses covering all of the priority pollutants. The Reichold outfall has received little sampling, since most of the attention has centered on the ditches downstream (the North Lincoln Avenue drain outfall has been sampled four times). The St. Regis pulp mill and U.S. Oil and Refining effluents have been tested for all priority pollutants on only one occasion.

In contrast to the generally good coverage of major dischargers, only two minor NPDES permitted discharges, Buffelen Woodworking and the St. Regis sawmill, have been sampled for all priority pollutants. Approximately 30 minor dischargers in the Commencement Bay area have NPDES permits. These dischargers should be prioritized by flow and industrial process, and the probable contributors of toxic substances sampled.

A point source and surface runoff observation file is presented in Appendix D. The source name, document number, location description, dates of sampling, flows, and concentrations of metals, total organic compounds, and selected organics have been entered into the source observation data base, and mass loadings computed and displayed. This file summarizes the spatial, temporal, and contaminant coverage of the point and runoff source data base. The information is organized by subarea, and system identification numbers were assigned to samples to classify them by waterway and drainage area. The observation file summarizes the spatial coverage of the point and runoff source data base, and is also useful in considering the consistency of temporal coverage.

Temporal Coverage of Contaminant Sources--Most of the reliable data on Commencement Bay contaminant sources is fairly recent. Some of the earliest data can be found in a Class II survey conducted at ASARCO in 1975 (Springer 1975). With this limited information it is impossible to accurately determine historical contaminant loadings from point and runoff sources. Crude estimates of historical mass loadings could be obtained by inspection of records of industrial outputs, processes, and waste disposal practices, but few corporations keep detailed records beyond 5 years. Therefore, discussion here will focus on temporal characterization of the present discharges, that is, the adequacy of the current data to describe daily, weekly, or seasonal variations in mass loadings of pollutants to the study area.

A striking characteristic of the temporal distribution of the sampling data is that only 18 of the 187 samples in the data base were collected outside of the period extending from March 29 through September 23. Thus, only 10 percent of the samples were taken during the wettest half of the year, and of these 18 samples only five were analyzed for all priority pollutants. In those cases where flow and contaminant data are available for both winter and summer, the metals and total organic contaminant concentrations in winter are generally equal to or greater than the dry season concentrations. This, coupled with wet season flows an order of magnitude greater than dry season, leads to mass loadings an order of magnitude or more higher than in summer. If other sources, particularly runoff sources, follow this pattern, then the bulk of the mass loadings of toxic substances from point and runoff sources have never been quantified. The lack of knowledge of wet season flows and pollutant concentrations stands out as the largest single data gap in the contaminant source data base.

Of the five wet season organics analyses, two were obtained from the east and west drains at the head of City Waterway. The remaining three were collected at the Tacoma Central sewage treatment plant, the Cleveland Street pump station, and the Puyallup River near the subarea boundary. No wet season organic contaminant samples have been taken from the other seven subareas.

During a storm event, pollutant concentrations typically peak early as the surficial contaminant-bearing deposits are flushed from drains, parking lots, roads, and the land surface. Grab samples have limited value in characterizing storm flow contaminants, so to gain a representative sample of the total mass loading from a storm event, samples should be composited in proportion to the flow rate. Most of the runoff samples of wet season flows were collected with composite samplers designed to draw an aliquot at specified time intervals. No information on the intensity and duration of storm events is available in the reviewed studies.

Contaminant Coverage--A complete listing of the pollutant source information file is presented in Appendix C. Included are data on the contaminant groups samples in each subarea during each study. Some of this information is summarized in Table 6, where contaminated information is displayed by waterway.

Consistency of contaminant coverage can be addressed by considering stations analyzed for metals only and those tested for most or all priority pollutants (Table 6). In general, stations were either tested for most of the 13 metals on the priority pollutant list or a complete priority pollutant analysis was conducted. Metals had the best sampling coverage, as nearly all of the samples were tested for metals concentrations. Hylebos and Blair Waterways have the greatest number of stations tested only for metals. These stations are at log sort yards or drains where organic pollutants are not likely to occur in significant concentrations, and the sampling of metals only is probably justified due to the high cost of a full priority pollutant scan. Flow data are missing at many of these stations, however, and where significant drainage areas or large pipe diameters suggest the potential for large volumes of storm runoff, full priority pollutant analyses are advisable.

Few stations in City Waterway and along Ruston Shoreline have been tested for the organic priority pollutants. Given the large numbers of drains and minor discharges, the lack of organics sampling in City Waterway is noteworthy. Further investigation into the need for additional priority pollutant sampling along the Ruston Shoreline is recommended.

Total suspended solids (TSS) concentrations have been reported for the major NPDES-permitted point sources. However, TSS measurements are available for only a few runoff sources. Many metals and organic priority pollutants adsorb to suspended particles, and knowledge of TSS levels facilitates prediction of the transport and fate of contaminants. The current limited TSS information hinders the development of pollutant pathway prediction models, and inclusion of TSS in the parameters sampled in future investigations is recommended.

Chlorinated butadienes (CBDs) other than hexachlorabutadiene (HCBD) are not included in the EPA priority pollutants and have rarely been analyzed

TABLE 6. RUNOFF, POINT SOURCE, AND GROUNDWATER SEEP CONTAMINANT COVERAGE BY SUBAREA

Subarea	Number of Stations Sampled for Metals and Organic Compounds	Number of Stations Sampled for Metals only	Total Number of Stations
Hylebos	36	12	48
Blair	18	14	32
Sitcum	2	0	2
Milwaukee	0	0	0
Puyallup	3	1	4
St. Paul	3	1	4
Middle	1	0	1
City	4	11	15
Ruston Shoreline	2	4	6
Totals	69	43	112

in point and runoff sources. Concern for CBDs found in sediments of the study area points out the lack of CBD source data.

Contaminant Mass Loadings--Mass loadings computed from the acceptable source data are given in the source observation file of Appendix D. Mass loadings were calculated in two ways: first, by multiplying flow by concentration, converting to units of lb/day, and then averaging the available mass loadings; second, by averaging flows and concentrations first and then performing the multiplication to determine the mass loading rate. Since concentrations are flow-dependent, the first method generally gives better results, but where flow and concentration data were collected on different dates the latter method was necessary. The mass loadings in the following discussion were all found using the first method. Where flow rates or concentrations were estimated, the computed mass loadings are given as estimates.

The major industrial point sources of toxic pollutants in Hylebos Waterway are Pennwalt, Occidental Chemical, and Sound Refining. The sewers, seeps, and main outfall at Pennwalt discharge an average of 5.3 lb/day arsenic, 0.99 lb/day chromium, 5.6 lb/day copper, 1.5 lb/day lead, 1.77 lb/day nickel, 2.2 lb/day selenium, 11.2 lb/day zinc, and smaller amounts of antimony and thallium, with nearly all of the loading from the main outfall. Approximately 13 lb/day of organic compounds, primarily chloroform and bromoform, are also discharged from the main outfall. The seeps and drains at Pennwalt have high toxic contaminant concentrations, but since the flow rates are a small fraction of the 11.2 MGD average flow at the main outfall, the mass loadings are small. Occidental Chemical contributes 1.13 lb/day arsenic, 8.9 lb/day chromium, 3.4 lb/day copper, 9.4 lb/day lead, 1.3 lb/day selenium, 1.3 lb/day zinc, and 4.4 lb/day of organic compounds, mainly volatile organics. Sound Refining has a small metals output, but contributes 0.78 lb/day of organics, including pentachlorophenol, benzene, 1,1,1-trichloroethane, and bis(2-ethylhexyl)phthalate.

The ditches with known significant inputs to Hylebos Waterways are Hylebos Creek, Kaiser ditch, and the drain opposite Lincoln Avenue. Hylebos Creek mass loadings include 4.8 lb/day arsenic, 4.0 lb/day zinc, some nickel, and between 0.43 and 1.9 lb/day of organic compounds. The Kaiser ditch emits moderate amounts of arsenic, copper, lead, nickel, and zinc (less than 1 lb/day of each), and 0.49 lb/day of organic compounds. The drain opposite Lincoln Avenue contributes negligible amounts of organics, but may have high loadings of copper, lead, nickel, and zinc (mass loadings were found by Method 2). Since wet-weather flow and concentration data are not available for nearly all of the runoff sources in Hylebos, this summary should be considered an incomplete portrayal of the true mass loadings. In contrast to the generally adequate coverage of point sources in Hylebos Waterway, runoff sources, with their variable and flow-dependent mass loadings, have not been adequately characterized.

Sampling of the two major point sources in Blair Waterway, Reichold Chemical and U.S. Oil and Refining, has not revealed high loadings of metals or organic contaminants. The known mass loadings originate from the north and south Lincoln Avenue drains, the Alexander drain (which drains most of the Reichold plant site), the drain at the west corner of the turning basin, and Wapato Creek. Of these sources, no one contributor accounts for a preponderance of the mass loadings. The Alexander and north Lincoln Avenue drains contain moderate amounts of arsenic, chromium, lead, nickel, and zinc; in fact, the similarities in the concentrations of these metals implicate the Alexander drain as the main source of pollutants to the north Lincoln Avenue drain. The south Lincoln Avenue drain emits moderate loadings of copper and lead, while the drain at the west corner of the turning basin contributes some arsenic and zinc, and Wapato Creek discharges copper, nickel, and zinc. The organic compound mass loadings of the five major runoff sources range from 0.17 lb/day at the west corner of the turning basin to 0.68 lb/day from Wapato Creek, for a total mass loading of slightly more than 2 lb/day. As in Hylebos Waterway, the lack of wet weather sampling precludes a complete accounting of pollutant mass loadings to Blair Waterway.

In Sitcum Waterway only the two drains at the head of the waterway have been sampled. The south corner drain had small mass emission rates for all contaminants, while the north corner drain recorded 0.6 lb/day arsenic, 0.42 lb/day lead, 1.08 lb/day zinc, and 0.24 lb/day total organic compounds (mostly volatiles). Future sampling of these two drains and others in Sitcum Waterway during high flows will probably show higher mass loadings of pollutants.

The Puyallup subarea is unique in that the high flows of the Puyallup River carry in large amounts of pollutants at low concentrations, but also provide flushing to remove contaminants. Thus, the contaminant loadings should be viewed in light of the shorter hydraulic residence time in the Puyallup subarea. Low but still detectable concentrations of pollutants in the Puyallup River combined with a high flow of 12,210 MGD to give mass loadings of 2,000 lb/day copper, 400 lb/day lead, 3,600 lb/day zinc, and 815 lb/day cyanide on February 16, 1982. By comparison, the Tacoma Central sewage treatment plant contributes an average of 4.0 lb/day arsenic, 3.2 lb/day chromium, 11.1 lb/day copper, 13.4 lb/day lead, 24.5 lb/day nickel, 44 lb/day zinc, and 52 lb/day total organic compounds, including 1.2 lb/day low molecular weight polynuclear aromatics (PNAs), 0.32 lb/day high molecular weight PNAs, and traces of PCBs and pesticides. The Cleveland Street pump station, sampled during high flows, contributed 14 lb/day arsenic, 94 lb/day copper, 85 lb/day lead, 94 lb/day zinc, and an estimated total of 5 lb/day cyanide and 1,2-dichlorobenzene. Pollutants from the Puyallup River are adsorbed onto suspended particles. Most of the suspended load settles near the mouth of the Puyallup River or is transported to Commencement Bay. A smaller portion of the suspended load is circulated into adjacent waterways by tidal movements. Thus, the Puyallup River probably affects adjacent waterways to a greater degree than any other subarea.

The limited amount of sampling in St. Paul, Middle, and Milwaukee Waterways has uncovered no major sources of contaminants. The St. Regis paper mill and sawmill have each been sampled once, with no notable contributions of toxic pollutants. Only one sample has been collected in Middle Waterway and none in Milwaukee Waterway.

To date, sampling in City Waterway has shown significant loadings only of metals. The major contributors were the two drains at the head of the waterway, where high winter mass loadings resulted in average emissions of 1.9 lb/day arsenic, 5.0 lb/day copper, 18.5 lb/day lead, 12.0 lb/day zinc, and a smaller contribution of nickel (0.4 lb/day). The 15th Street drain produced 0.18 lb/day of arsenic, 0.49 lb/day copper, 0.76 lb/day lead, and 0.43 lb/day zinc. The drain at the head of Wheeler-Osgood Waterway had mass loadings of 0.17 lb/day of lead, 0.29 lb/day of zinc, and very small amounts of several other metals. The measured organics contribution came almost entirely from the two drains at the head of City Waterway, a loading of 0.42 lb/day total, consisting primarily of cyanide and trichloroethylene with traces of anthracene. The drain at the head of Wheeler-Osgood produced small amounts of organic substances, including some anthracene and phenanthrene. From these low mass loadings, particularly of organic compounds, it is evident that significant sources have remained unquantified in City Waterway.

Large mass loading rates of metals have been measured at the ASARCO outfalls along Ruston Shoreline. Even without the south outfall, which does not discharge directly to Commencement Bay, the mass emissions rate of arsenic is 39.2 lb/day. Large amounts of copper (28.0 lb/day) and zinc (16.2 lb/day) are also discharged. The ASARCO outfalls have not been tested for organic pollutants, but a variety of organic pollutants (4.9 lb/day) have been measured at the Tacoma North sewage treatment plant, including 1.4 lb/day of hexachlorobutadiene (HCBD) and trace amounts of hexachlorobenzene (HCB), pesticides, and both high and low molecular weight PNAs. In addition, moderate amounts of arsenic (1.1 lb/day) and copper (2.5 lb/day), and considerable amounts of zinc (14 lb/day) are discharged from the Tacoma North sewage treatment plant. Since only two of the numerous drains along Ruston Shoreline have been sampled, little is known about the contribution made by these sources.

Ongoing Studies on Point and Runoff Sources--To complement past studies of contaminant sources, WDOE has initiated or proposed investigations in areas where pollutant problems have been identified but the existing data are not sufficient to quantify sources. These studies are described in Krull (1983), and are summarized here:

- Log Sort Yards as Metals Sources. ASARCO slag has been used for ballast at 11 log sort yards in the tideflats area. Runoff flows and pollutant concentrations will be measured.

- Hylebos Creek Drainage Metals Sources. This proposal includes the identification and measurement of metals inputs to Hylebos Creek.

- Monitoring of Major Non-NPDES Sources. Additional sampling will be carried out at six drains, with six samples taken at each of the following: the west drain at the head of City Waterway, the south Lincoln Avenue drain into Blair, the Kaiser ditch, and the north corner drain in Sitcum Waterway. One dry- and one wet-weather sample will be collected at Hylebos Creek and the Morningside drain.

- Identification of Metals Sources to Sitcum Waterway Sediments. An unspecified number of samples may be collected as part of this study.

- Metals and Organic Priority Pollutant Sources to City Waterway Sediments. Dry- and wet-weather samples and flow measurements will be taken at major drains in City Waterway.

- Completion of the TPCHD Drainage System Investigation. Drains, seeps, and channels along Ruston Shoreline and in the Hylebos and Wapato Creek drainages are being identified, described, and mapped.

The City Waterway, Sitcum Waterway, and Hylebos Creek investigations should aid in filling contaminant source data gaps. No information on station locations is given in the brief study descriptions available, so a complete review of the capability of these studies to close data gaps is not possible. The ongoing studies will be considered further, along with recommendations on methods for station selection, in the discussion of the contaminant source study design.

Contaminant Inputs from Spills--

Information on spills entering the study area waters was obtained from two sources. Ground spills reported to WDOE are investigated and the reports are filed in the environmental quality files of the WDOE Southwest Regional Office in Tumwater. Marine spills are reported to the U.S. Coast Guard, and two computer listings were obtained, one from the local district office and the other from the Washington, D.C., office. Marine spill information from 1973 to 1983 was available.

Spill reports in WDOE files usually contain information on the time, date, and location of the spill, an estimate of the volume or mass spilled, the spilled substance, and measures taken to clean up the material. Estimates of the volume of material reaching waterways or ditches are often rough guesses (being described as "very small," "minor amount," or an estimated volume), or the amounts are not reported at all. Spill reporting relies on citizen reports or the understanding and compliance of the party responsible for causing the spill, and there are no reliable estimates of the frequency and amounts of unreported spills.

The U.S. Coast Guard spill inventory lists the longitude and latitude, material, quantity, date, and source of the spill. Spills are located to the nearest minute of longitude and latitude, making it impossible to unambiguously locate spills, or, in some cases, even determine which waterway the spill impacted. The amount of recovery is not given, so net loadings cannot be determined.

In summary, spill data gaps are the following:

- Spill locations are not precisely reported

- The net mass loadings are not known, either because they are not quantified or the recovery effectiveness is not given

- The potential amount of unreported spills, particularly of substances that are not visibly traceable, is not known.

Groundwater Sources--

The data and data gaps on groundwater sources contributing to the study area are now considered. First, an overview of the groundwater regime in the Tacoma port area is presented, then the general area-wide level of desired information is described and compared to currently available data. The existing site-specific studies are then summarized and assessed as to their adequacy in providing the information necessary to quantify mass loadings of contaminants to the study area. Estimated loadings from sites with sufficient data are presented, followed by a list of possible additional sources of groundwater contamination that may warrant investigation.

The groundwater regime in the Tacoma port area consists of two aquifers in sandy zones separated by silt layers. In some locations, a perched zone is present where permeable fill material is underlain by silt. Water from these perched zones can seep into the waterways. The fill material can be up to 25 ft thick. The silty layer, when present below the fill, consists of sandy to clayey silt zones, typically 20 to 40 ft thick. The middle sand zone varies from 20 to about 150 ft in thickness and can include discontinuous silt zones. The fill material directly overlies the sand in some areas. Below the middle sand is another silt zone and a deep zone of sands with interbedded silts.

The flow regime in the port area is influenced by the tides. Groundwater in the shallow aquifer generally flows toward the waterways. The depth-to-water ranges from 0 to 10 ft near the bay and from 10 to 50 ft toward the southeastern part of the port area. However, at high tide, the flow direction can be reversed for areas close to the waterways. Such a reversal occurs in areas along Hylebos Waterway. The deeper aquifer is under confined conditions and discharges into Commencement Bay. Pressures in the aquifer are high enough to cause wells drilled into this aquifer to flow. Because of the flow regime, wastes reaching the groundwater can enter the waterways and bay.

Industrial activity in the port area has resulted in disposal of process wastes. Because of the long history of development in this area, determining the source of a given observed contaminant is especially difficult. Compounding the problem is the use of ASARCO slag as fill in some areas and use of other industrial wastes and dredge spoil deposits as fill in other areas (Dames and Moore 1982). Present activities may be incompatible with the nature of the fill deposits. For example, log sorting operations on areas of ASARCO slag have caused leaching of arsenic and other heavy metals into the soil and subsequently into the waterways. Sites where contamination of soils or groundwater is known or is suspected are shown in the Tideflats Land Use Survey (Dames and Moore 1982). The tideflats survey identified 117 industrial sites, of which 49 areas were selected as sites where hazardous wastes may be present. Of these, over 20 sites may be affecting groundwater and, thus, the waterways.

The initial obstacle to defining the groundwater contamination potential of the study area as a whole is the lack of groundwater flow information. A study of the geology of the Port of Tacoma, prepared by Hart Crowser and Associates, Inc. (No Date), provides cross sections of the stratigraphy of the natural and filled deposits, but does not include groundwater level measurements. A general water level map of the study area, with well locations of completed, ongoing, or anticipated studies, would be useful as a basis for decisions on the adequacy of completed or ongoing studies in accomplishing their stated objectives. In addition, the groundwater level map is essential for predicting the fate of known contaminants at sites that have not undergone groundwater study, and also for estimating the potential impacts on specific waterways of suspected subsurface contaminants. Thus, the groundwater map would aid in evaluating completed or ongoing studies, in designing additional detailed studies at sites with known contaminants, and in prioritizing suspected contaminated sites for additional study. The last goal could be accomplished by linking potentially contaminated sites with "hot spots" in sediments receiving groundwater from the direction of the suspected site.

In addition to the groundwater level map, estimates of total groundwater flow to the waterways would be useful in eventually determining pollutant loadings to the waterways. Data for the groundwater mapping and measurements of the total contributory groundwater flow could be obtained by a synoptic water level survey, preferably with water level measurements at both high and low tides since water levels and flow directions are tidally influenced. To obtain a general picture of the total mass loadings of pollutants to the waterways, a synoptic survey of some indicators (total dissolved solids, pH, arsenic, total organic hydrocarbons) could be conducted in conjunction with the water level survey.

Specific information needed at sites of groundwater contamination includes detailed water level maps, estimates of groundwater flow rates and velocities, a list of contaminants of concern, contaminant concentration data, and estimates of mass loadings to the waterways involved. Ideally, the data on detectable contaminants can be presented in the following format:

- Concentrations in groundwater
- Concentrations in the tributary waterways
- Toxicity thresholds, acute and chronic
- Concentrations for cancer risks.

Mass loadings of contaminants can be summarized as follows:

- Total load in the unsaturated zone
- Total load in the saturated zone
- Total combined load
- Estimated flow rate into the waterway
- Estimated loading into the waterway

- Predicted concentration in waterway
- Hydraulic flushing time to leach material out of unsaturated zone
- Time and number of volumes to remove 50 percent of sorbed contaminants.

Based on data available for this review, only two sites, Occidental Chemical and Pennwalt, have sufficient data for this kind of presentation.

A summary of the reviewed Commencement Bay groundwater studies is presented in Table 7. The bulk of the acceptable data has been collected at Pennwalt, Occidental Chemical, and the area of oil migration into City Waterway near D Street. Data from Georgia Pacific (formerly Pacific Resins and Chemicals) were rejected due to inadequate documentation of sample collection, handling, and storage techniques and no description of QA/QC procedures. For similar reasons, data from Allied Chemicals were also found to be unacceptable for inclusion in the data base. Limited data were available for Kaiser Aluminum, Occidental Chemical's off-site waste disposal areas, U.S. Oil and Refining, and the Chempro/Lilyblad site. The Pennwalt, Occidental, City Waterway, Georgia Pacific, and Kaiser studies contain sufficient information to define the groundwater flow regime, but only at the first two sites are groundwater contaminant concentrations quantified so that mass loadings can be determined. The estimated total loading of organic pollutants to Hylebos Waterway from Occidental Chemical is 6 to 12.5 lb/day, and Pennwalt contributes 1.08 lb/day of metals and 0.24 lb/day of chloroform.

Information on the temporal coverage of groundwater investigations is displayed in Table 8. All of the data have been collected in the past 5 years, so there is a limited historical record of movement of toxic pollutants that were present in the past but have since been flushed out into the waterway. It may be possible to infer a connection between past groundwater contamination and present waterway sediment contamination by comparing

TABLE 7. SUMMARY OF GROUNDWATER SOURCE DATA

Document	Site Name	Well Location	Geologic Cross-Sections	Water Level Maps	Hydraulic Conductivity	Ground-water Velocity	Waste Source Characterization	Waste Source Map	Soil Samples		Groundwater Concentrations		
									Unsaturated	Saturated	Shallow	Intermediate	Deep
Shannon and Wilson, Inc. (1981)	Pennwalt	Y[a]	Y	C	N	N	N	N	N	N	Y	Y	Y
AWARE, Inc. (1981)	Pennwalt	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Hart Crowser and Associates (1980a)	Occidental Chemical	Y	Y	N	Y	C	Y	Y	Y	N	Y		Y
Walker Wells, Inc. (1980a)	Occidental Chemical	Y	N	Y[b]	N	N	N	N	Y[b]	N	Y[b]		Y[b]
Pacific Resin and Chemical (1983)	Georgia Pacific	Y	Y	Y	N	N	Y	Y	Y	N		Data limited, not acceptable for data base	
Hart Crowser and Associates (1983)	Allied Chemical	Y	Y	Y	Y	Y	N	Y	N	N		Data not accepted	
Monahan (1982)	Kaiser Aluminum	N	N	N	N	N	N	N	N	N		Limited data available	
Kaiser Aluminum (1983)	Kaiser Aluminum	Y	N	N	N	N	N	N	N	N		Preliminary results	
Hart Crowser and Associates (1982a)	City Waterway Oil Migration	Y	Y	Y	Y	C	Y	N	N	N		N	
Feller et al. (1981)	Hooker-offsite waste disposal	N	N	N	N	N	Y	Y[c]	N	N		N	
Chemical Processors (1982)	ChemPro/Lilyblad	Y	N	N	N	N	N	N	N	N	Y	Well depths not specified	
Hart Crowser and Associates (1982b)	U.S. Oil & Refining	Y	N	N	N	N	N	N	N	N		Preliminary results	

[a] Y = data available, N = data not available, C = can be calculated.

[b] Water level map constructed from data in Hart, Crowser & Associates (1980a).

[c] Estimated.

TABLE 8. TEMPORAL COVERAGE OF SITE-SPECIFIC INVESTIGATIONS

Document	Site Name (Waterway)	Number of Water Level Measurements	Date of Water Level Measurements	Date of Chemical Sampling: Organics	Date of Chemical Sampling: Metals
Shannon and Wilson, Inc. (1981)	Pennwalt (Hylebos)	21	4/30 & 5/1/81	4/28 & 8/14	same
AWARE, Inc. (1981)	Pennwalt (Hylebos)	30 total	7/3/81	7/2, 8/13, 9/24/81	same
Utting et al. (1979)	Hooker Chemical (Hylebos)	9 sites, both shallow & deep	11/19/79	9/11-17/79	none
Hart Crowser and Associates (1980a)	Hooker Chemical Phase II (Hylebos)	12	6/26-7/2/80 8/13-14/80	8/12-13/80	none
Hart Crowser and Associates (1980b)	Hooker Chemical Phase III (Hylebos)	--	--	10/31/80 soil unsaturated zone only	none
Pacific Resin and Chemical (1983)	Pacific Resin & Chemical Georgia Pacific (Puyallup)	10	9/2-3/81	Phenol only, 4 times in 1981	none
Hart Crowser and Associates (1983)	Allied Chemical (Puyallup)	4	7/15/83	--	2/16/83 data not accepted
Monahan (1982) Kaiser Aluminum (1983)	Kaiser Aluminum[a] (Hylebos/ Blair)	--	--	Fluoride, cyanide only on 10/14/81, 7/81, 11/82, 3/83, and 6/83	
Hart Crowser and Associates (1982a)	City Waterway	17	7/9/82, 8/2/82	Oil only 7/9/82, 8/2/82	
Huntamer (1982)	"D" Street (City)	--	--	5 wells 6/10/82	none
Chemical Processors (1982)	ChemPro (Blair)	12	--	8/5/82 Phenols, PCBs	Cyanide Cr, Ni

[a] Based on past disposal practices at site, dump site southwest of plant for cyanide and metal waste needs more detailed investigation.

residuals in soil samples to any corresponding high concentrations of the same pollutants in downgradient sediments. To date, however, no such links have been conclusively established, and not enough is known about the persistence of historical contaminant deposits in the subsurface soils and transport rates to the waterways.

Recognizing the lack of data on groundwater contamination in the study area, WDOE has requested or ordered a number of industries to perform groundwater and soils investigations (WDOE 1983a). Ongoing studies are currently being conducted at the following sites:

- Kaiser Aluminum
- Allied Chemical
- Chempro/Lilyblad
- U.S. Gypsum
- Union Pacific Railroad Yard
- U.S. Oil and Refining

In addition, WDOE has requested a groundwater and soils investigation at Reichold Chemical. The following facilities have completed studies and also have ongoing monitoring programs:

- Occidental Chemical
- City Waterway Oil Migration
- Georgia Pacific

Additional monitoring is anticipated at Pennwalt. The additional data produced by these efforts should greatly increase knowledge of groundwater contamination in the study area.

There are, however, many other sites where additional investigation is justified. From descriptions of historic land use in the study area (Dames and Moore 1982), a list of additional sites with potential for groundwater contamination was developed (Table 9). This list was compiled by considering the nature and extent of known or suspected subsurface materials. Soil boring data should be obtained at these sites and used to determine where further groundwater investigation is advisable. Contaminants present in the various old dump sites which may be leaching to groundwater and the waterways, include pesticides, oil, cyanide, arsenic, formaldehyde, PCBs, polyaromatic hydrocarbons, methylmercuric phosphate, and other heavy metals and organic chemicals. Presence of metals and toxic organic contaminants complicates remedial activities since these contaminants can sorb onto soils and sediment. Additional pore volumes of fresh water are required to flush out these contaminants by desorption, or, alternatively, the contaminated soils can be excavated and deposited at a site where further leaching is prevented.

Airborne Sources--

The Puget Sound Air Pollution Control Agency (PSAPCA) has estimated point source air emissions for 1982 for all significant point sources in the Commencement Bay area (PSAPCA 1983). The emissions parameters are total suspended particulate matter (TSPM), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), volatile organic compounds (VOC), and carbon monoxide (CO). The parameters SO_x, NO_x, and CO do not directly influence the water quality of the waterways, so they are not considered further. Emissions of contaminated particulates and VOC may, on the other hand, represent a pathway of pollutant transport to the Commencement Bay waterways. A first-order estimate of pollutant loadings from airborne pollutants is presented here to determine the significance of this source.

According to data supplied by the PSAPCA, a total of 22 significant point sources emitted 3,378 tons of suspended particulate matter in 1982. A significant source is defined as one which emits at least 25 tons/yr

TABLE 9. POSSIBLE ADDITIONAL SOURCES OF GROUNDWATER CONTAMINATION

Site Number[a]	Present Owner/Lessee	Subarea Potentially Impacted	Type of Contamination
1	Airo Services	Hylebos	Metals
3	Sound Oil and Refining	Hylebos	Oil, organics
23	Murray Pacific Log Yard (discussed in Pierce 1982)	Hylebos	Iron alloy, ASARCO slag for fill and deposition of metals from old furnace
26	Buffelen Woodworking	Hylebos	Phenols, formaldehyde glue waste
31	Don Oline (discussed in Feller et al. 1981)	Hylebos/Blair	Old industrial dump
35	Fletcher Oil	Hylebos	Oil
37	Zidell Marine	Hylebos	Dump site
38	Todd Chemical	Blair	Paint solvents
47	Stauffer Chemical	Blair	$AlSO_4$, seepage from old ponds
57	Port of Tacoma Cargo Vans	Blair/Sitcum	Metals, oil, organics
63	Port of Tacoma	Puyallup	Old city dump
68 & 79	Milwaukee Rail Yard	Milwaukee	Seepage from oil and other spills
81	St. Regis Sawmill	St. Paul	Phenols (glues)
98	Joseph Simon & Sons	Puyallup	PAHs
99	Standard Oil	City (?)	Oil
107	N. Pacific Plywood	City	Phenols (glues)
113	Puget Sound Trucking	Puyallup (?)	Old pond sites, glues, resins, chemicals
115	Lindal Cedar Homes	Hylebos (?)	Methylmercuric phosphate
36a	Offsite Disposal of Hooker Chemical wastes (discussed in Feller et al. 1981)	Hylebos/ Puyallup	Toxic organics, metals, asbestos
41a	Offsite Disposal of Fill and ASARCO Slag from Site 41 (J.A. Jones Construction)	Blair/Puyallup	Metals
---	Sites where ASARCO Slag used at Log Sort Yards (discussed in Pierce 1982)	Hylebos/Blair	Metals, As

[a] Numbers are from Dames & Moore (1982).

of one or more of the pollutant parameters listed above. The point sources include those in the Commencement Bay waterway area and the ASARCO smelter.

Next, it is assumed that 10 percent of the total annual emissions or 338 tons are deposited in the waterways. This is probably a conservatively high percentage because only 30 to 40 percent of the particles may ever impact ground level within the project area and the waterways are on the order of 10 percent of the project surface area. This is compensated by not considering fugitive dust in this estimate.

The average pollutant concentration of the particle is assumed to be 100 ppm (mg/kg). This concentration is higher than the lead and arsenic concentration of ASARCO slag. With this assumption, 1 ton of contaminated particulate matter is equivalent to 0.2 lb of pollutant.

The total surface area of the waterways is about 3 km^2. The total pollutant load to the waterways would therefore be:

$$\frac{338 \text{ ton/yr} \times 0.2 \text{ lb pollutant/ton}}{3 \text{ km}^2} = 22.5 \text{ lb/km}^2\text{/yr}$$

or

$$\frac{22.5 \text{ lb/km}^2\text{/yr}}{365 \text{ days/yr}} = 0.06 \text{ lb/km}^2\text{/day}$$

For the largest waterway, Hylebos, this loading would be:

$$0.06 \text{ lb/km}^2\text{/day} \times 1.2 \text{ km}^2 = 0.07 \text{ lb/day}$$

This is an extremely small loading. Even if the loading was an order of magnitude greater, 0.7 lb/day, the loading would be negligible.

The PSAPCA is currently performing chemical analyses of suspended particulate matter collected in the Tacoma industrial area (J. Nolan, personal communication). The results of these analyses will allow a better estimate of the pollutant loading to the waterways from airborne sources. While the above estimate assumes a pollutant concentration of 100 mg/kg for airborne particles, the actual concentrations of specific pollutants is expected to be much lower.

The total loading of volatile organic compounds (VOC) in 1982 has been estimated by the PSAPCA to be 2,311 tons. Nearly all of these emissions are very light weight hydrocarbons, hexane or lighter, and do not contribute directly to the toxic pollutant load in the waterways. These compounds in the gaseous state are not subject to significant wash out during rainfall events. The percentage of VOC molecules which would impact the ground or water surface is probably on the order of 1 percent. The volatile organic compound loadings from point source emissions are considered to be insignificant to the waterway pollutant loading because of their composition and small loading.

Contamination and Effects

The data evaluation for studies of contamination and effects covered a total of about 50 documents, which contained information from 78 studies (Table 10 and Appendices B and C). Approximately 56 percent of the studies were considered acceptable for the data base. The majority of the rejected studies had severe limitations in their analytical methods; sample collection, handling, or storage was also inadequate for most of the rejected studies. Acceptable data on benthic invertebrate ecology, zooplankton ecology, and phytoplankton ecology are not available. Therefore, these study types (categories) are not discussed further below. Summaries of the results of most studies are available in Dexter et al. (1981), Konasewich et al. (1982), and Tetra Tech (1982). In addition, the Decision Criteria Report provides a review and analysis of relevant studies. Therefore, study results will not be reviewed extensively below.

TABLE 10. SUMMARY OF AVAILABLE INFORMATION FOR STUDIES OF CONTAMINATON AND EFFECTS

Study Type	No. Available Studies			Data Base		
	Accept[a]	Reject[a]	Total	No. Studies/ Areas[b]	No. Items[c]	Product
Sediment Quality	14	1	15	43	24	1,032
Water Quality	13	0	13	38	24	912
Bioaccumulation	8	3	11	27	18	486
Pathology	3	2	5	15	3	45
Fish Ecology	4	4	8	32	3	96
Benthic Invertebrates	0	8	8	0	--	0
Zooplankton	0	1	1	0	--	0
Phytoplankton	0	2	2	0	--	0
Bioassay Effects	2	13	15	22	9	198
TOTAL	44	34	78	177	--	2,769

[a] Accept and reject indicate total numbers of studies accepted or rejected for the Commencement Bay data base.

[b] No. studies and areas within studies considered acceptable for data base. This number equals the total number of rows with information in the sampling intensity matrix, or the number of lines in the computer summary file for each study type (see Appendix C).

[c] No. items is the number of individual cells within a row of the sampling intensity matrix. For example, eight columns were relevant to sediment quality studies. Since three items (No. stations, No. times, No. samples) was scored per column, a total of 24 items of information was collected for each matrix row. Only one column (WQ) was relevant for studies of pathology and ecology.

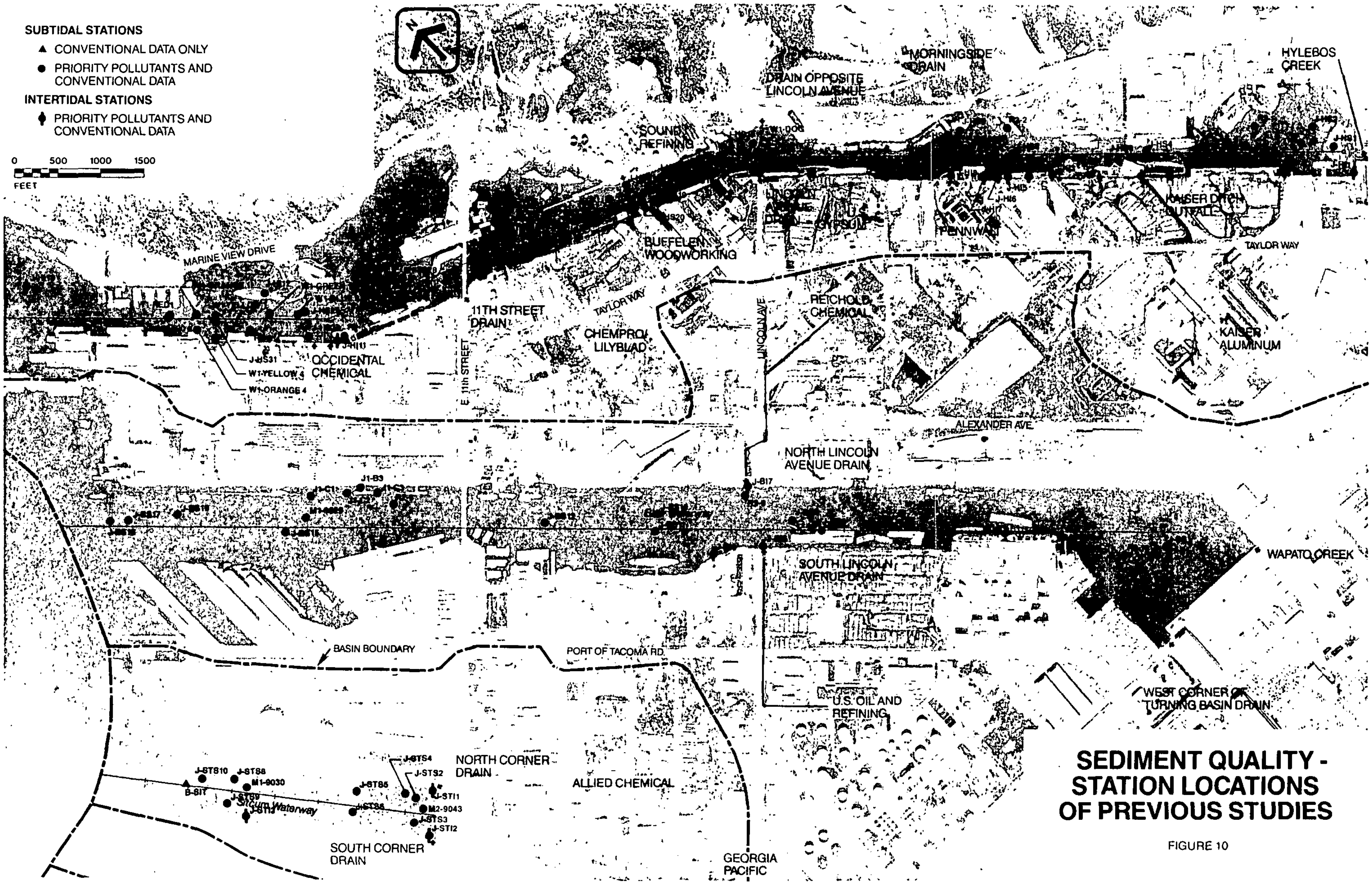
Sediment Quality--

Considerable information is available on sediment contamination in the study area and throughout Puget Sound. WDOE has analyzed for priority pollutants in an extensive series of surface sediment samples collected from the study area as part of the Class II receiving environment surveys. Johnson et al. (1983a-e) summarize the WDOE information, unpublished results of previous EPA studies, and results of NOAA programs (Riley et al., 1980, 1981; Malins et al., 1980, 1982). In addition, data on arsenic and mercury in Commencement Bay and potential reference areas were obtained by Crecelius et al. (1975). Although Crecelius et al. (1975) did not sample within the waterways, their data provide a regional assessment of sediment contamination resulting from ASARCO smelter emissions. Hileman and Matta (1983) analyzed surface sediment samples from 45 stations in deep water (greater than 100 ft) areas of Commencement Bay. Since all of their samples were outside the primary study area, the data of Hileman and Matta (1983) are not included in the analyses below. Available information on conventional sediment parameters (e.g., percent organic content, grain size composition) is summarized in Appendix C.

Station locations for sediment quality studies are shown in Figures 10-13. Stations in Figures 10-13 and subsequent maps of station locations are identified by a primary character code keyed to the author(s)' last name, followed by a hyphen and the station name (or code) used by the original author(s) (Table 11). It was necessary to create a new primary code, rather than simply using the document number to key stations to a particular author, because of the limited space available on the station maps. In some cases, the first letter of the first author's last name was sufficient to form a unique primary character code. If it was not sufficient, then the first letter of the first author's last name is followed by one or more characters in the sequence:

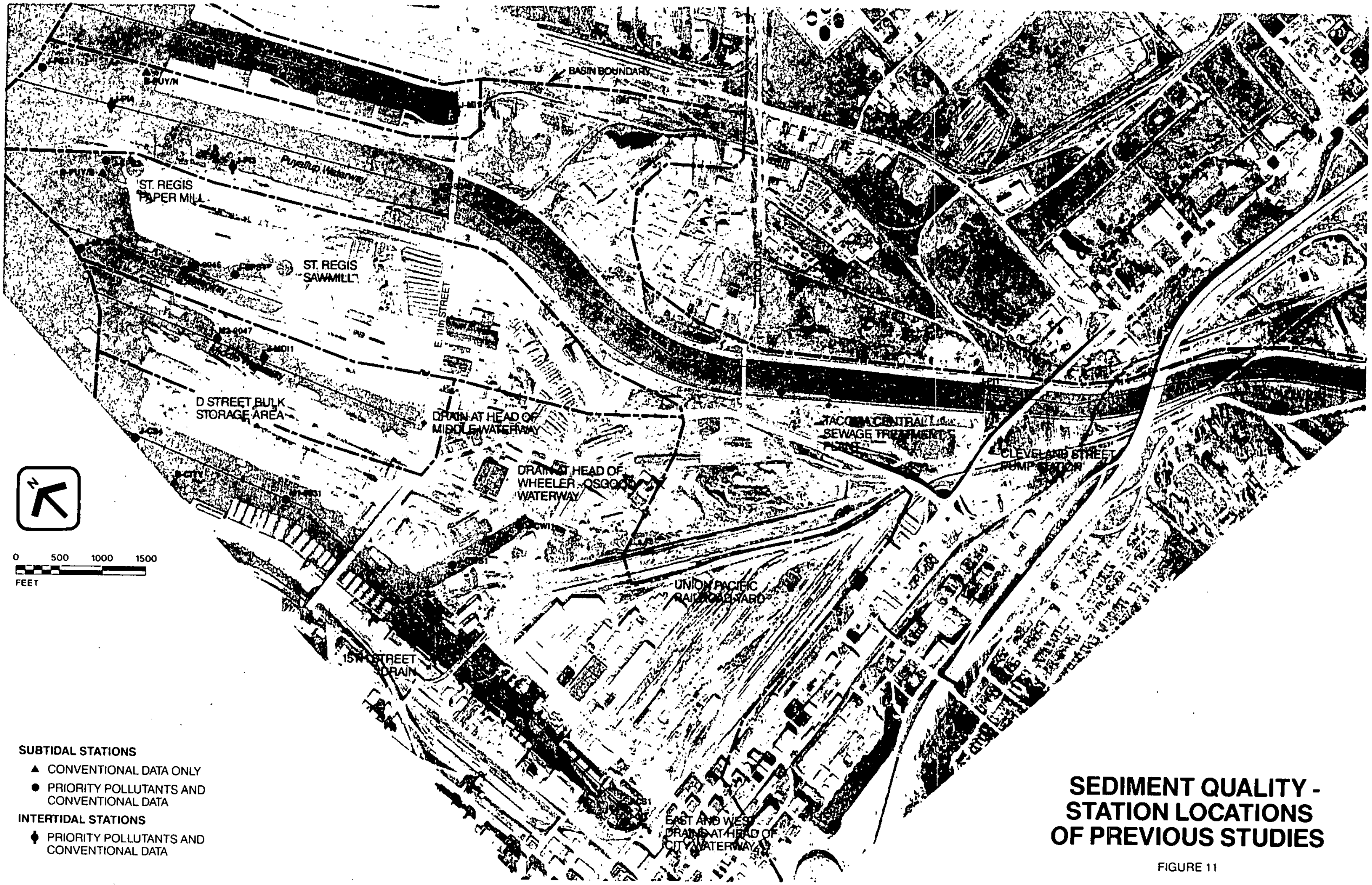
1a. First letter of second author's last name

1b. First letters of successive authors' last names



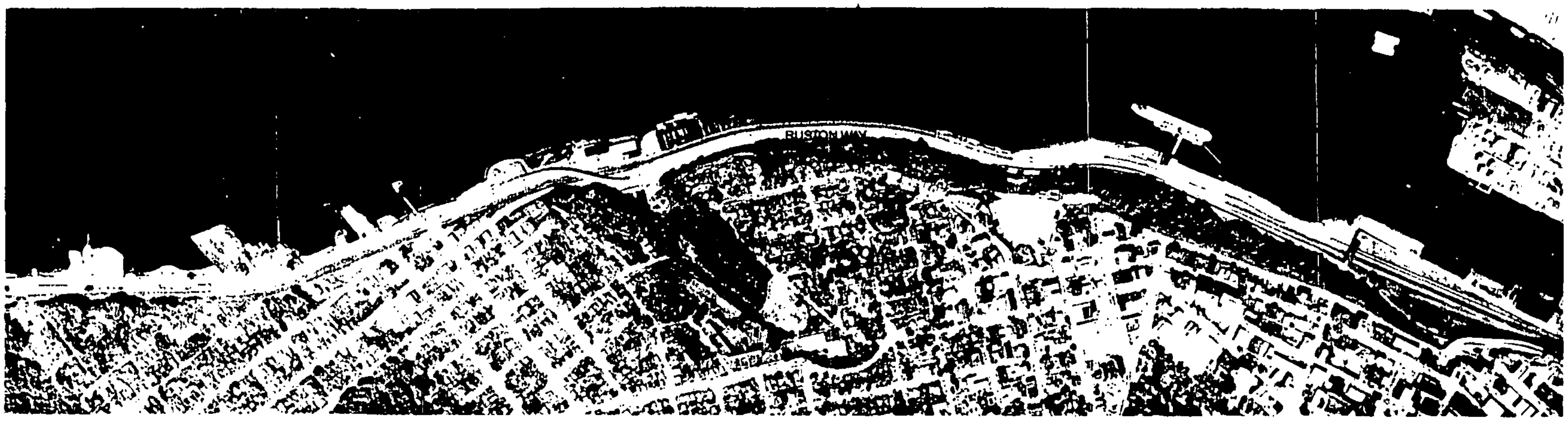
SEDIMENT QUALITY - STATION LOCATIONS OF PREVIOUS STUDIES

FIGURE 10



SEDIMENT QUALITY - STATION LOCATIONS OF PREVIOUS STUDIES

FIGURE 11



WATER QUALITY
- ● PRIORITY POLLUTANTS & CONVENTIONAL DATA

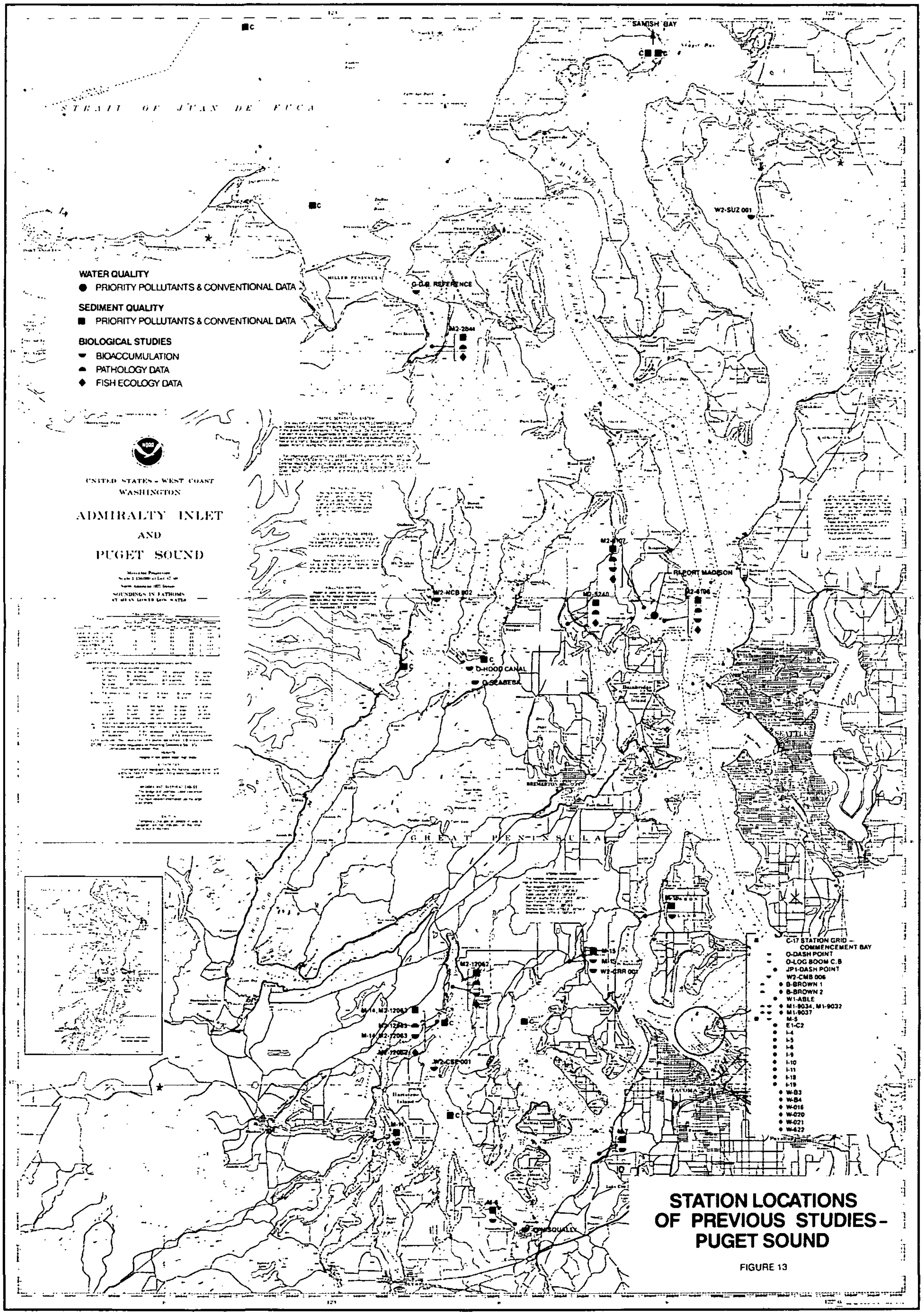
SEDIMENT QUALITY
- ■ PRIORITY POLLUTANTS & CONVENTIONAL DATA

BIOLOGICAL STUDIES
- BIOACCUMULATION
- PATHOLOGY DATA
- ◆ FISH ECOLOGY DATA

0 500 1000 1500
FEET

STATION LOCATIONS OF PREVIOUS STUDIES - RUSTON SHORE

FIGURE 12



STATION LOCATIONS OF PREVIOUS STUDIES - PUGET SOUND

FIGURE 13

TABLE 11. STATION IDENTIFICATION CODES USED ON MAPS OF PREVIOUS SAMPLING LOCATIONS

Station Code[a] Author Designation	Author-Date	Document No.
B	Becker and Chew 1983	BECK002F
B1	Bernhardt 1979	WDOE029F
B2	Bernhardt 1982a	WDOE002F
B3	Bernhardt 1982b	WDOE007F
C	Crecelius et al. 1975	CREC001F
CL	Cloud 1979	WDOE006F
E1	EPA 1980a	EPAb002F
E2	EPA 1980b	EPAb003F
G	Gahler et al. 1982	GAHL001F
H	Hufford 1981	HUFF001F
I	Isakson and Loehr 1981	DAME003F
J	Johnson et al. 1983a-e	JOHN001F JOHN002F JOHN003D JOHN004D JOHN005D
JP1	Johnson and Prescott 1982c	WDOE001F
JP2	Johnson and Prescott 1982b	WDOE004F
JP3	Johnson and Prescott 1982d	WDOE023F
JP4	Johnson and Prescott 1982a	WDOE025F
M	Mowrer et al. 1977	MOWR001F
M1	Malins et al. 1980	MALI002F
M2	Malins et al. 1982	MALI003F
O	Olsen and Schell 1977	OLSE101P
R1	Riley et al. 1980	RILE001F
R2	Riley et al. 1981	RILE002F
W	Weitcamp and Schadt 1981	DAME005F
W1	WDOE 1981-83	WDOE015P
W2	WDOE 1983b	WDOE017P

[a] On the station location maps, primary character codes for author designation are followed by a hyphen and the station code used by the author cited above.

2a. Second letter of first author's last name

2b. Successive letters of first author's last name

3. If the name(s) of (all) the author(s) occurred on more than one document, then the first letter of the first author's last name was followed by an index number (1, 2, 3, or 4, etc.) corresponding to the chronological order of the document date. In the case of undated multiple documents by the same author(s), the numerical sequence in the document code was used to order the documents and a corresponding index number was assigned.

In assigning station codes, the above sequence was followed until a unique primary character code was obtained for a particular document. If no station code was available from the original author, then each station for that document was assigned only a primary character code for present purposes.

Approximately 112 sediment quality stations were located in the waterways, including 27 intertidal sites. In past studies, stations have been positioned in areas adjacent to known point sources or in expected trouble spots. Consequently, some areas within some waterways (e.g., Hooker Chemical site in Hylebos Waterway, and Lincoln Avenue drains in Blair Waterway) have received intensive coverage while some entire waterways have been sampled at only one or two sites (e.g., Milwaukee, St. Paul, and Middle Waterways; Ruston Shore). In addition, several subareas within the Puyallup River and Hylebos, Blair, and City Waterways have not received adequate spatial coverage. The degree of sediment contamination has been assessed at 21 reference sites throughout the Puget Sound region (Figure 13). Within each reference area, however, the spatial coverage has not been extensive.

Data from deep sediment cores (greater than 5-10 cm) have been obtained in only three of the reviewed studies. Johnson (1983) summarized data from four 6-ft long sediment cores and one 2-ft long core taken from the Port of Tacoma proposed dredging project area in Blair Waterway. Riley et al. (1981) reported concentrations of chlorinated biphenyls, chlorinated butadienes, PAHs, and selected aromatic hydrocarbons in sediment cores taken from six sites in Hylebos Waterway and four sites in Blair Waterway (Figure 10). Their cores ranged from 25 to 40 cm in length. Finally, Crecelius et al. (1975) presented profiles of arsenic concentrations in sediment cores (15-50 cm long) taken from Quartermaster Harbor, East Passage, and Puget Sound near Fox Island and north Seattle. Historical data on contaminant concentrations in sediments of the waterways are therefore scarce. Moreover, surficial sediments have been sampled only once at most sites.

An index of sampling intensity normalized by waterway area is shown in Figure 14. The total number of samples taken in sediment quality studies for a contaminant group in a given waterway was divided by the area of the waterway. The data used to construct these indices and corresponding data on the total number of samples taken in deepwater portions and shorelines of Commencement Bay and in reference areas are given in Appendix E. From Figure 14, it is clear that Hylebos, Sitcum, and St. Paul Waterways have been sampled most intensively relative to waterway size. Nevertheless, only two surface sediment samples have been collected from St. Paul Waterway. Volatile organic compounds and acid extractable organic compounds have received little attention in Blair Waterway. This trend is reflected in the total number of samples analyzed for these contaminant groups in all sediment studies (Table 12). Relative to other contaminant groups, the fewest data gaps exist for metals, PCBs, and base-neutral organic compounds.

Data recommended for inclusion in the data base should be interpreted with caution. For example, the extensive data set of Malins et al. (1980, 1982) may be useful for comparison of broad areas (e.g., among waterways, or between a given waterway and a reference area), but limitations of their sampling methods prevent linking the data to specific sampling sites. Malins et al. (1980, 1982) composited sediment cores from two of three benthic grab samples taken at each of their "stations." The three grabs were taken at different depths at some stations, and the depths of composited samples were not given.

	ME	VO	BN	AE	PC	PE
HY	40	42	46	16	46	33
BL	22	6	21	6	19	14
SI	62	43	62	43	62	58
MI	9	9	9	9	9	9
SP	34	34	34	34	34	34
MD	21	10	21	10	21	21
CI	23	8	23	8	18	18
PU	9	7	9	7	9	9

> 50

25-50

0-24

Note: Sampling Intensity Index = $\frac{\text{Number of Samples}}{\text{Waterway Area } (10^{-6}\ m^2)}$

Figure 14. Index of sampling intensity for sediment quality studies.

TABLE 12. SUMMARY OF SEDIMENT QUALITY STUDIES: CONTAMINANT COVERAGE

	Contaminant Group					
Index	Metals	Volatile Organics	Base/Neutral Organics	Acid Extractable Organics	PCBs	Pesticides
No. Stations[a]	156	70	126	46	144	100
No. Times[a]	36	10	33	8	31	17
No. Samples[a]	163	78	141	46	144	100

[a] Numbers are totals of all waterways, Commencement Bay, and reference areas from Appendix C. Station values are slight overestimates (<10%) because the same stations sampled at different times and reported in different documents are counted twice (e.g., MALI002F and MALI003F in Appendix C).

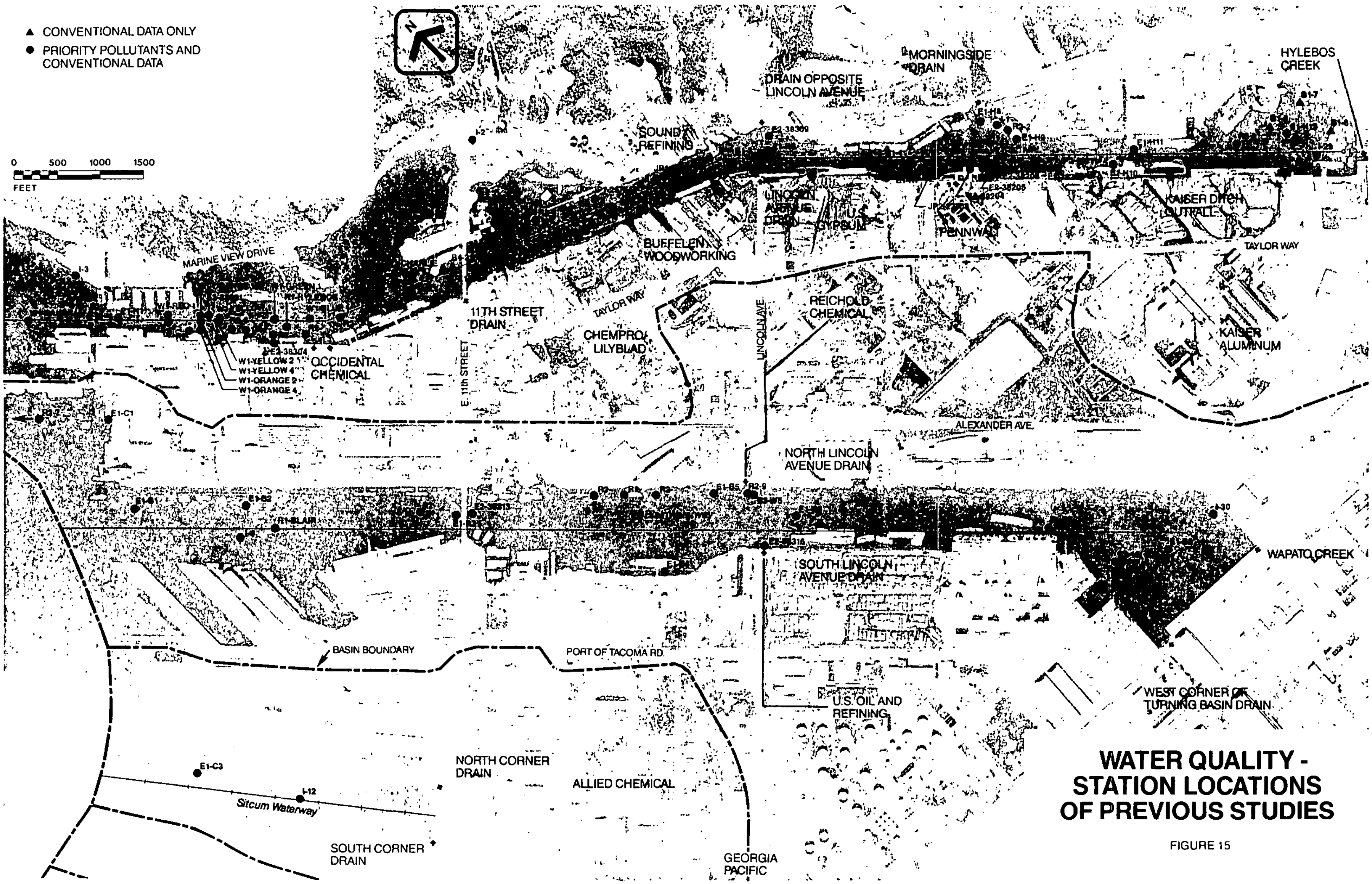
Limitations of some analytical methods also place restrictions on interpretation of the sediment data. For example, most analyses of volatile organic compounds in sediments may have been inadequate. Research conducted by METRO has shown that more than 100 g of wet sediment are necessary for accurate analyses of volatile compounds. In past studies, analyses were typically conducted on smaller sediment samples. In WDOE studies, CBDs were underestimated in samples collected before March 31, 1982 (Johnson and Prescott 1982c). One of the two studies of deep sediment cores in Blair Waterway (Johnson 1983) shows the high variability associated with contaminant concentration data. As part of that study, QA/QC analyses by Hart-Crowser Labs showed that percent recovery for organic contaminants ranged from about 40-450 percent.

Water Quality--

Most studies of water quality reviewed during the data evaluation phase focused on suspected problem areas near point discharges in the Commencement Bay waterways. For example, seven studies were conducted as part of WDOE Class II receiving water surveys. These studies examined concentrations of conventional pollutants (e.g., nutrients, phenols, suspended solids) in grab samples and priority pollutants in composite samples, as well as ancillary water quality parameters (e.g., temperature, salinity, dissolved oxygen concentrations). Each Class II survey was conducted in the immediate vicinity of a major point discharge, including Hooker Chemical Corporation (WDOE 1981-1983), the Sound Refining facility (Johnson and Prescott 1982c), Reichhold Chemical, Inc. (Bernhardt 1982b), U.S. Oil and Refining Co. (Bernhardt 1982a), Pennwalt Corporation (Johnson and Prescott 1982b), St. Regis Paper Co. (Johnson and Prescott 1982a), and the Tacoma Central Wastewater Treatment Plant (Johnson and Prescott 1982d). Corresponding surveys of effluent quality to determine NPDES permit compliance and pollutant loadings to the receiving environments were also conducted (see above, Sources, Point Discharges).

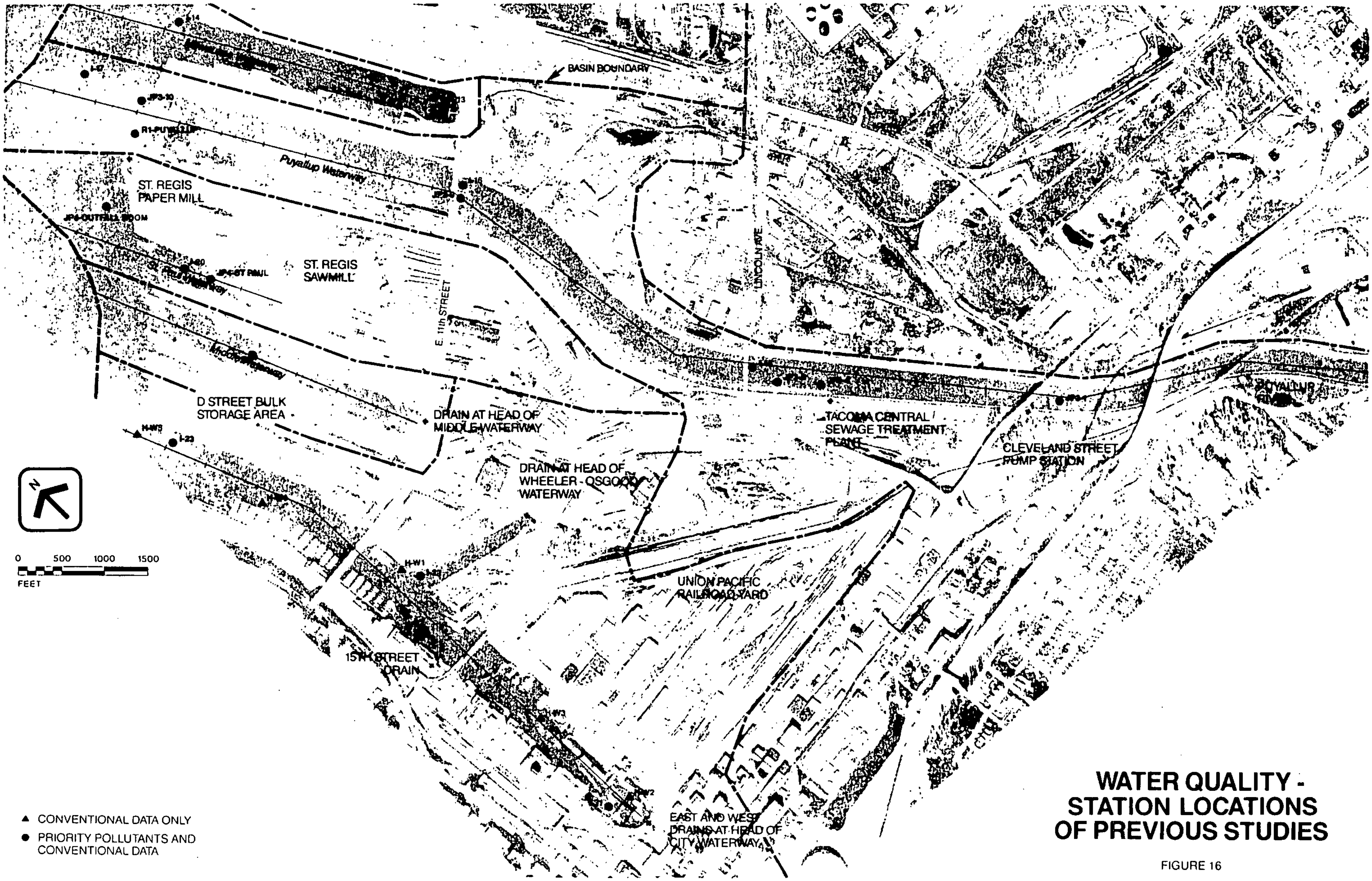
Other water quality investigations in the study area have generally been more comprehensive than the Class II surveys in terms of spatial coverage. Isakson and Loehr (1981) examined conventional pollutants, six metals, and ancillary parameters (temperature, salinity, chlorophyll a, dissolved oxygen, pH, and turbidity) at a total of 18 stations in the waterways, 5 stations along the Ruston Shore and Old Tacoma, and 8 stations in deepwater portions of Commencement Bay. Their study was conducted during two periods (October 1-3, December 16-17, 1980) and included investigations of depth stratification of all parameters at selected sites. Three depths (surface, middle, bottom) were sampled at most sites, although additional depths were sampled for some ancillary parameters. EPA Region X conducted water quality surveys of a total of 38-40 conventional and priority pollutants at approximately 30 stations in Hylebos, Blair and Sitcum Waterways and a "control" station near Browns Point on June 3 and September 23-24, 1980 (EPA 1980a,b). Grab samples were taken at the water surface at each station, and additional samples were taken at 20 ft below the surface at selected stations. Riley et al. (1980, 1981) conducted studies of metals, halogenated organic compounds (HCBD, PCBs), purgable organic compounds, and aromatic hydrocarbons in suspended matter and water taken from Blair Waterway, Hylebos Waterway, the Puyallup River, and Port Madison.

Station locations for water quality studies are shown in Figures 13, 15, and 16. A total of 112 stations were located in the Commencement Bay waterways (including 13 stations where only data on conventional pollutants or ancillary parameters were collected). Note that only one reference station (Port Madison) was sampled by the studies reviewed here. In general, Hylebos, Blair, and City Waterways have received adequate spatial coverage, while sampling has been restricted to only a few areas in other waterways. Sitcum Waterway, St. Paul Waterway, and the Ruston Shore have been sampled at only a few sites each. Spatial coverage has been particularly poor in Milwaukee and Middle Waterways, where samples taken from three stations have been analyzed only for conventional pollutants and ancillary data. Although many studies examined variation in parameter values with water depth, the relationships between circulation patterns in the waterways and depth profiles of conventional and priority pollutants in the water column have not been elucidated. In general, samples have been taken at predetermined depths unrelated to patterns of salinity and temperature stratification at the time of sampling.



WATER QUALITY - STATION LOCATIONS OF PREVIOUS STUDIES

FIGURE 15



▲ CONVENTIONAL DATA ONLY

● PRIORITY POLLUTANTS AND CONVENTIONAL DATA

WATER QUALITY - STATION LOCATIONS OF PREVIOUS STUDIES

FIGURE 16

Temporal coverage of water quality studies in Commencement Bay has been inadequate for a comprehensive characterization of seasonal changes in water column parameters. Most Class II receiving water surveys were conducted on only a single date. Other studies were restricted to less than three dates. Seasonal variations in water quality and the influence of the Puyallup River on conditions in each of the waterways have not been defined in the studies reviewed here. Nevertheless, it should be recognized that an intensive search of the literature for studies of only conventional pollutants and ancillary parameters in Commencement Bay and its waterways was not conducted. It is possible that compilation and review of the latter studies would reveal more details of temporal variation in water quality, at least for conventional and ancillary parameters.

An index of sampling intensity normalized by waterway area is shown in Figure 17. This index is analogous to the one presented earlier for sediment quality studies (Figure 14). Raw data on the number of samples taken in each area for each contaminant group are presented in Appendix E. Recall that depth profile samples are not incorporated into the analysis here for reasons discussed in the above section entitled Data Evaluation Procedures. Relative to waterway size, Hylebos and St. Paul Waterways are the only areas that have been adequately sampled in terms of spatial coverage (Figure 17). Nevertheless, St. Paul Waterway has been sampled at only two stations for analysis of contaminant concentrations. The biggest data gaps exist in Milwaukee and Middle Waterways, where none of the reviewed studies determined priority pollutant concentrations. Acid extractable organic compounds, PCBs, and pesticides have each been analyzed in only two or three waterways (samples of total phenols are included under conventional pollutants in Appendices B and C). However, acid extractable organic compounds are not expected to persist in the water column. Riley et al. (1981) observed PCB concentrations ranging from 0.02 to 0.54 ppb in filtered water from Blair and Hylebos Waterways. Although none of the individual concentrations exceeded the EPA acute criteria value of 10 ppb, 30 of the 31 values exceeded the chronic criteria value of 0.03 ppb. Further data are necessary to clarify the importance of PCBs in waters of the study area. Collection of additional data on pesticides may not be warranted, since their concen-

	ME	VO	BN	AE	PC	PE
HY	30	92	48	2	25	2
BL	20	25	23		7	1
SI	10	10	10			
MI						
SP	34	34	34	34		
MD						
CI	8					
PU	20	20	16	14		14

> 50

25-50

0-24

Note: $\text{Sampling Intensity Index} = \dfrac{\text{Number of Samples}}{\text{Waterway Area } (10^{-6}\ m^2)}$

Figure 17. Index of sampling intensity for water quality studies.

trations in the water column are generally low or undetectable in the study area (Riley et al., 1981; Johnson et al., 1983a, c).

A summary of contaminant group coverage by the water quality studies is shown in Table 13. Overall, acid extractable organic compounds, PCBs, and pesticides have been sampled less intensively in time and space than other contaminant groups. Interestingly, volatile organic compounds have received more attention than the relatively persistent metals and base/neutral organic compounds.

A severe limitation of the water quality data base is the failure of most past studies to partition pollutant concentrations into dissolved and particulate fractions. Only Riley et al. (1980, 1981) systematically determined pollutant levels in suspended matter and filtered water. Other limitations on interpretation of data arise from incompatible or inaccurate methods. Johnson and Prescott (1982c) note that CBD concentrations have probably been underestimated in water samples analyzed by WDOE before March 31, 1982.

Bioaccumulation--

Studies of contaminant concentrations in organisms collected from Commencement Bay and its waterways have been limited. The most extensive set of data are found in Malins et al. (1980, 1982) and Gahler et al. (1982). These studies examined a large number of priority pollutants in demersal fishes, crabs, and benthic infauna from the study area and from reference areas (e.g., Discovery Bay, Port Madison, Case Inlet). Gahler et al. (1982) compared contaminant levels in "bottom" fishes (English, rock, flathead, and C-O sole; starry flounder), "off-bottom" fishes (walleye pollock, Pacific hake, Pacific tomcod, and Pacific cod), and "mixed" fishes (Pacific staghorn sculpin, buffalo sculpin, rockfish, and whitespotted greenling). Useful data from other studies (WDOE Class II receiving water surveys and mussel watch portion of the Basic Water Monitoring Program; Mowrer et al. 1977; Olsen and Schell 1977; Cummins et al., 1976; and Price 1978) are primarily concerned with bioaccumulation in soft tissues of the bay mussel (Mytilus edulis) or other bivalve molluscs, although fishes were studied to a limited

TABLE 13. SUMMARY OF WATER QUALITY STUDIES: CONTAMINANT COVERAGE

	Contaminant Group					
Index	Metals	Volatile Organics	Base/Neutral Organics	Acid Extractable Organics	PCBs	Pesticides
No. Stations[a]	57	72	71	9	30	8
No. Times[a]	27	34	28	5	9	5
No. Samples[a]	84	164	101	12	39	11

[a] Numbers are totals of Commencement Bay, all waterways,and reference areas from Appendix C. Station values are slight overestimates (<5%) because some stations were sampled twice and reported in different documents (e.g., EPA 1980a, b).

extent.[1] Most studies examined a broad range of contaminants. However, Mowrer et al. (1977) analyzed only PCBs; and Olsen and Schell (1977) reported on concentrations of metals only. Each of the reviewed studies compared data on tissue levels of contaminants in Commencement Bay or its waterways with reference data, although the latter data were sometimes obtained from another investigator.

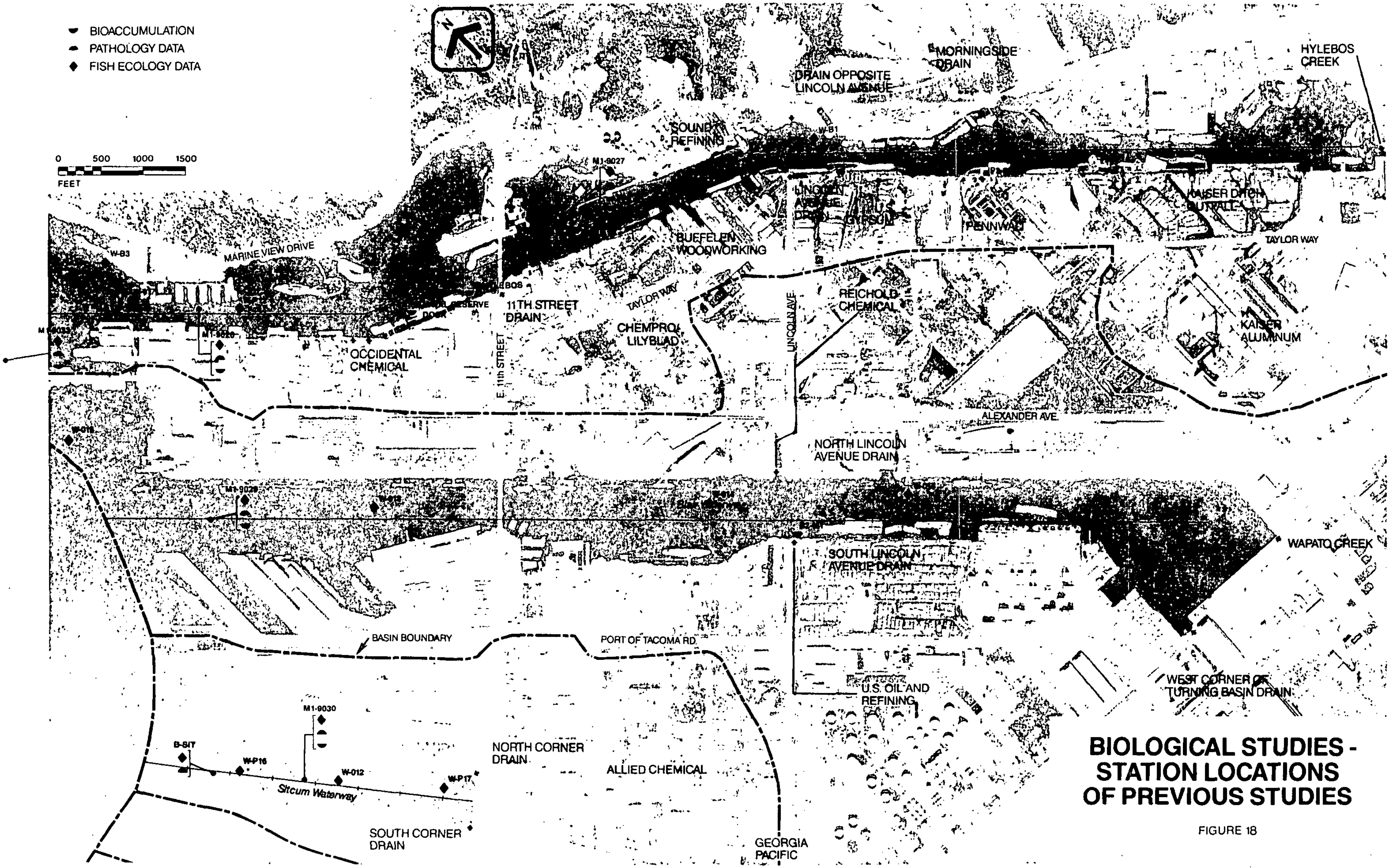
Some bioaccumulation studies have been limited by a failure to relate contaminant levels in tissues to the degree of pollution of water or sediments at the same sites where organisms were collected (e.g., Olsen and Schell 1977; Cloud 1979; Gahler et al., 1982). Although Malins et al. (1980, 1982) attempted to establish relationships between sediment quality and concentrations of contaminants in tissues, their analyses are limited because some samples were composited over a wide range of depths (and possibly sediment characteristics). WDOE (Bernhardt 1982a; Johnson and Prescott 1982b) has analyzed for contaminant concentrations in concurrent samples of biota, sediment, and in some cases water, but their sampling program has been limited in space and time.

Little information is available on metabolites of the priority pollutants. In past studies, no effort was made to analyze for metabolites of pollutants. Thus, contaminants that have been found in tissues may be those which are especially resistant to biodegradation. Finally, bioaccumulation studies of whole organisms have generally been limited by a failure to fractionate contaminants into separate compartments associated with gut contents and with tissues (i.e., nonassimilated vs. assimilated contaminants). Studies of whole organisms did allow organisms to void gut contents before analyses were conducted.

The locations of stations sampled by the bioaccumulation studies are shown in Figures 13, 18, and 19. With the exception of Hylebos Waterway and portions of City Waterway, spatial coverage of the bioaccumulation studies is poor over most of the study area. Moreover, past sampling stations

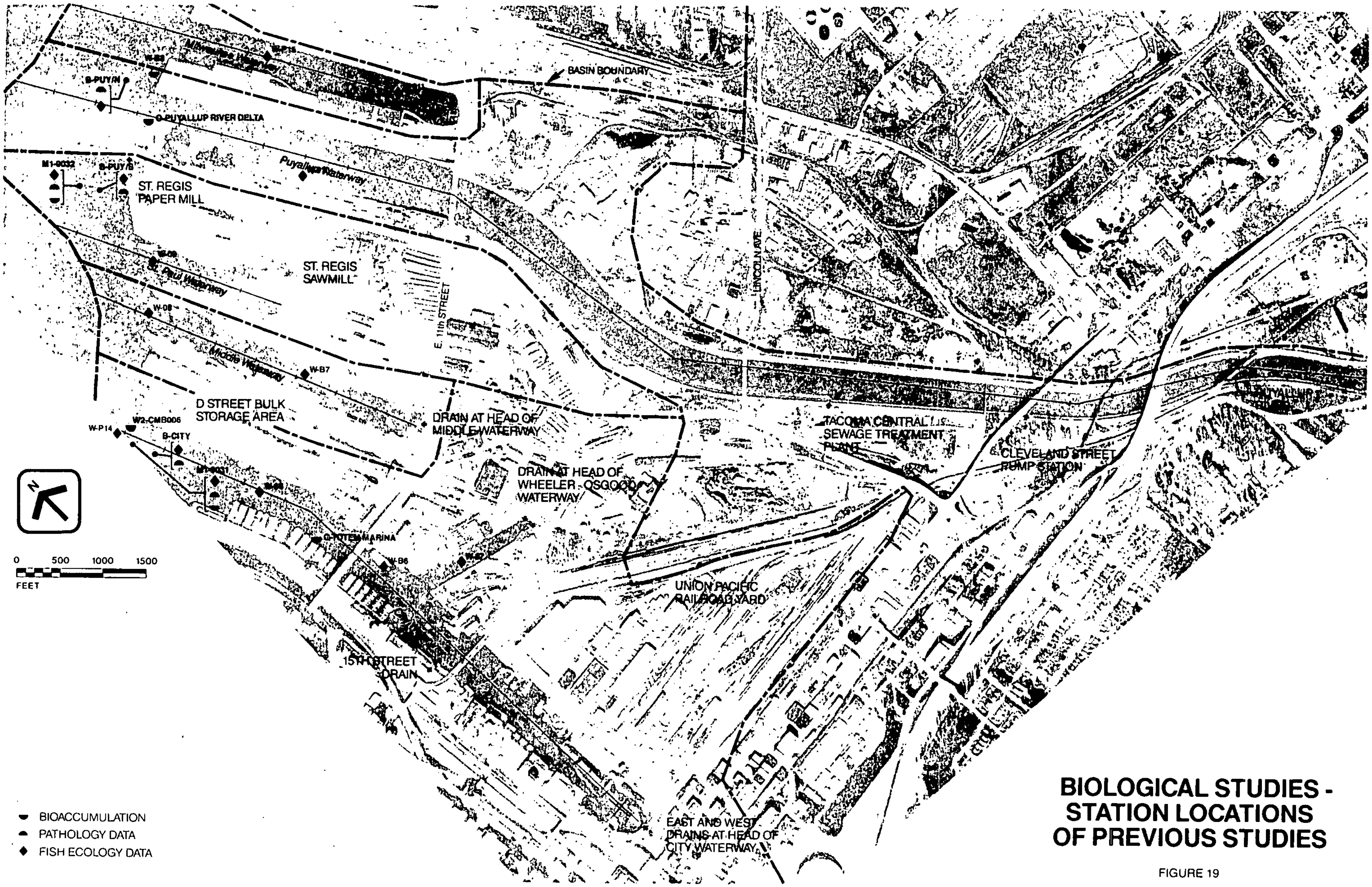
---

[1]The studies by Price (1978) and Cummins et al. (1976) were not obtained in time to be incorporated into the computer file (Appendix C) and summary tables presented below. Both studies contain tissue contamination data that may be useful to the Commencement Bay project.



BIOLOGICAL STUDIES - STATION LOCATIONS OF PREVIOUS STUDIES

FIGURE 18



BIOLOGICAL STUDIES - STATION LOCATIONS OF PREVIOUS STUDIES

FIGURE 19

are concentrated near the mouths of the waterways. In contrast to the poor spatial coverage of the study area, bioaccumulation sampling stations at reference sites have been distributed throughout the Puget Sound region.

Temporal coverage of the bioaccumulation studies is extremely limited. Only two of the eight studies reviewed here had information for more than one sampling date. Seasonal or year-to-year variations in contaminant levels in samples of organism tissues from the study area have not been addressed.

An index of sampling intensity analogous to those presented for other study types discussed above is shown in Figure 20. Supporting data are presented in Appendix E. These data suggest that City Waterway has been sampled adequately for most contaminant groups. Hylebos Waterway has received considerable attention with respect to PCBs and pesticides. Bioaccumulation in other waterways has not been assessed adequately. Although many samples have been taken for metals, PCBs, and pesticides near ASARCO, other contaminant groups have received little attention there. Moreover, the high potential for metals contamination and the poor spatial and temporal coverage of past sampling at the ASARCO site dictate that further work is necessary. Overall, reference areas have been sampled more intensively than most portions of the study area. Discovery Bay has been studied extensively relative to other reference sites.

Contaminant coverage during the bioaccumulation studies is summarized in Table 14. Metals, PCBs, and pesticides have been well studied relative to other contaminant groups. Further research on base-neutral organic compounds in organism tissues is necessary. Although volatile organic compounds and acid extractable organic compounds have not been analyzed extensively in bioaccumulation studies, these chemicals within these groups are not expected to persist at high levels in organisms.

Biological Effects--

Indigenous Organisms--Acceptable data on communities of benthic infauna, phytoplankton, and zooplankton in the project area are not available.

TABLE 14. SUMMARY OF BIOACCUMULATION STUDIES: CONTAMINANT COVERAGE

	Contaminant Group					
Index	Metals	Volatile Organics	Base/Neutral Organics	Acid Extractable Organics	PCBs	Pesticides
No. Stations[a]	30	5	16	8	24	15
No. Times[a]	26	5	17	10	21	16
No. Samples[a]	183	93	115	32	177	168

[a] Numbers are totals of all waterways, Commencement Bay, and reference areas from Appendix C. These values do not include Malins et al. (1982) because of poor documentation of sample identity and reporting of only composite sample data in the original reference.

	ME	VO	BN	AE	PC	PE
HY	17	12	23	2	26	25
BL	3					
SI	10					
MI						
SP						
MD						
CI	64	61	28	28	59	59
PU	2					

heavy-bordered box	> 50
shaded box	25-50
plain box	0-24

Note: $$\text{Sampling Intensity Index} = \frac{\text{Number of Samples}}{\text{Waterway Area } (10^{-6}\ m^2)}$$

Figure 20. Index of sampling intensity for bioaccumulation studies.

Useful studies of the biological effects of pollution on indigenous organisms in the study area are limited to three studies of pathology in fishes and invertebrates and four studies of fish ecology. The total sampling intensity represented by these studies is summarized in Table 15. Aside from the attempts of Malins et al. (1980, 1982) to relate contaminant levels in sediments to pathological conditions and ecological parameters of demersal fishes, the relationship between the degree of contamination and biological responses of field populations is poorly known. Data from Malins et al. (1982) were difficult to summarize, since the station locations or other identifiers for individual samples (which were incorporated into composite samples) were not reported. Thus, the numbers shown in Table 15 are only approximate. Raw data collected by Malins et al. (1980, 1982) are being retrieved from NODC.

The locations of sampling stations for studies of pathology and fish ecology are shown in Figure 13, 18, and 19 above. Numbers of stations, times, and samples for each area are presented in Appendix C. All portions of the study area have been sampled for assessment of the distribution and abundance of fishes, with the greatest numbers of stations occurring in Hylebos (10 stations), Blair (6 stations), and City (6 stations) Waterways, and along the Ruston Shore (7 stations). In contrast, pathological conditions have been analyzed at only a few sites in the study area: Blair Waterway (1 station), City Waterway (2 stations), Hylebos Waterway (2 stations), and Sitcum Waterway (2 stations). Data gaps on pathological conditions in organisms from Milwaukee, Middle, and St. Paul Waterways and the Ruston Shore are apparent.

Temporal coverage of biological effects studies has generally been adequate. Becker and Chew (1983) and Malins et al. (1980, 1982) sampled four times corresponding to seasonal periods. In addition, Becker and Chew (1983) sampled 2 diel periods at each of their sites and 4 diel periods during spring at Browns Point, City Waterway, and Sitcum Waterway. Weitcamp and Schadt (1981) sampled juvenile salmonids a total of 8-19 times at each of seven project areas (City, Hylebos, Blair, Sitcum, Middle, and Milwaukee Waterways, and Ruston Shore). Other fishes were sampled by otter trawl during four seasons in all of the waterways and at Ruston Shore (Weitcamp

TABLE 15. SUMMARY OF BIOLOGICAL EFFECTS STUDIES

Index	Study Type	
	Pathology	Fish Ecology
No. Stations[a]	27	63
No. Times[a]	70	236
No. Samples[a]	154	593

[a] Numbers are totals of all waterways, Commencement Bay, and reference areas from Appendix C. Values are approximate; see text for explanation.

and Schadt 1981). Temporal coverage of pathology studies has been less extensive than that of fish ecology studies. Nevertheless, the existing data base allows some comparison of pathological conditions among seasons (Malins et al. 1980, 1982; Becker and Chew 1983).

Bioassay Effects--Four functional categories of bioassay were reviewed (see Decision Criteria Report for details). Assays of toxicity (acute, subacute, chronic, and subchronic) as well as carcinogenicity and mutagenicity from each of four categories were considered. The categories were:

- Whole sediments: surface samples
- Whole sediments: 60-cm composite samples
- Suspended matter and elutriates
- Water column.

Tetra Tech recommends the following three bioassays as most applicable to evaluation of sediment contamination in Commencement Bay:

- *Rhepoxynius abronius* - acute lethality (Swartz et al., 1982a,b)
- *Salmo gairdnerii* - genotoxicity (Chapman et al., 1982c).
- *Monopylephorous cuticulatus* - subacute respiration (Chapman et al., 1982c).

Summary

Data on the Commencement Bay waterways, Ruston Shore, and reference areas were compiled and evaluated from approximately 78 studies. Approximately 56 percent of reviewed studies were considered acceptable for inclusion in a Commencement Bay data base. Information on spatial coverage, temporal coverage, and sampling intensity of studies recommended for inclusion in the data base is summarized by area and by contaminant group for each study type.

Based on the existing data base, the total amount of information on contaminant concentrations in various media (sediments, water, and biota) is summarized in Table 16. Overall, total spatial and temporal coverage has been greater for sediment quality studies than for water quality or bioaccumulation studies. (If different sampling depths in the water column had been taken into account, the spatial coverage of water quality studies would be greater than that of other study categories). Sampling intensity appears to have been greater for bioaccumulation studies than for other study types. However, recall that a sample for bioaccumulation was considered as an individual organism or organism tissue (or corresponding composite sample). For sediment and water quality studies, an individual benthic grab or a water-bottle sample was regarded as the sampling unit. Also, note that the numbers in Table 16 represent the number of contaminant group analyses for all stations all times and all samples. Actual numbers of stations, times and samples are given for each contaminant group in Tables 12-14.

In general, the amount of information available (e.g., total number of samples analyzed) for contamination of various media by metals, PCBs, and base neutral organic compounds is greater than that available for pesticides, volatile organic compounds, and acid extractables. The latter compounds have been poorly studied for all media. Exceptions to these major trends are: 1) volatile organic compounds have been well sampled in the water column, and 2) pesticides have been analyzed in almost as many organism or tissue samples as metals and PCBs. Past studies have covered suspected problem areas more intensively than other sites. Thus, Hylebos, Blair, and City Waterways have been sampled much more than other portions of the study area. The Ruston Shore has received little attention relative to its importance as an area of potentially high contamination.

Various methodological and conceptual problems of past studies place limits on the interpretation of the existing data base. These limitations are:

TABLE 16. SUMMARY OF DATA COVERAGE FOR CONTAMINANT CONCENTRATIONS IN VARIOUS MEDIA

Index Sum	Water Quality	Media Sediment Quality	Bioaccumulation
No. Stations[a]	247	642	98
No. Times[a]	108	135	95
No. Samples[a]	411	672	768

[a] Numbers are sums of rows from Tables 12, 13, and 14.

- Comparability of data from different studies is limited by differences in methods, station locations, and temporal coverage among studies.

- Analytical methods resulted in detection limits that were too high (e.g., some organic priority pollutants) or underestimation of contaminant concentrations (volatile organic compounds in most studies; CBDs in WDOE studies before March 31, 1982).

- Concurrent sampling for conventional pollutants or ancillary data was not conducted in some studies of contamination, thereby limiting the establishment of causal mechanisms for biological effects.

IDENTIFICATION OF DATA GAPS

The following sections summarize the major data gaps in the existing information base for the Commencement Bay project. Data gaps were identified by consideration of the spatial and temporal coverage of the existing data for various pollutant groups and project subareas, as discussed in the previous sections under Evaluation Results. At the same time, data gaps were defined relative to three categories of information necessary to meet the goals of the project: 1) information required as input to the Decision Criteria, 2) information required to satisfy the specific objectives of Tasks 3 and 4 of the EPA/WDOE Cooperative Agreement, and 3) background data for a general characterization of physical-chemical parameters, conventional pollutants, and toxic contaminants in each of the project subareas. Thus, the data gaps identified below represent the key items of missing information, which should be obtained before a final plan for remedial action is developed.

Physical Processes

While some data are available on circulation within Commencement Bay and the waterways, only a general understanding can be gained. As in most similar systems, considerable variability in circulation patterns can be expected with changing tide, wind, density structure, and runoff conditions. Complete understanding of circulation within the system would require extensive long-term data collection efforts. The need for additional data collection and more detailed understanding of waterway and bay circulation must be assessed relative to the overall objective of the program which is to determine the need for and selection of remedial action required to mitigate adverse effects of toxic pollutants in the waterways.

The assessment of the need for additional circulation studies must be based on our present understanding of the distribution of toxic pollutants in the waterways and the bay. If pollutants entering the waterways are distributed widely, to Commencement Bay and other waterways, then more detailed knowledge of pollutant transport processes is needed to understand the relationships between pollutant sources and sinks (sediments). The cause and effect relationship which explains observed high sediment contamination concentrations is the central issue in developing remedial action plans.

Alternatively, specific toxics pollutants may not be widely distributed but generally concentrated in localized "hot spots" which can be related to a nearby source. Concentrations of the specific pollutants may be acceptably low throughout the remaining area of the waterway. In this case, the waterway can be considered as a closed system with respect to the bay and other waterways. If most of the toxic pollutants discharged to a waterway are transported to the sediments of the same waterway, then larger scale circulation patterns are not a concern.

The distribution of toxic pollutants appears to be quite patchy, with localized "hot spots," within individual waterways based upon the existing sediment quality data. Although these data are incomplete, it does not indicate that extensive additional circulation data are needed to understand the causal linkage for observed concentrations of toxic pollutants in sediments. For example, nearly all of the known hexachlorobutadiene (HCBD) discharged to Hylebos Waterway originates from point and runoff sources at Pennwalt Chemical Corporation. HCBD has also been detected in the sediments near the Pennwalt facility but only at stations within less than about 300 m of the plant. This type of pollutant distribution supports the position that pollutants are not widely distributed throughout the bay and waterway system from a single source.

It is recognized that an evaluation of contaminant transport and fate represents an important part of the assessments required under Tasks 3 and 4 of the EPA/DOE Cooperative Agreement. It is also recognized that currently available information do not enable a conclusive evaluation of the potential transport of contaminants among study subareas and into other parts of Commencement Bay. In lieu of conducting extensive circulation studies, two other kinds of information have been identified that will provide insight into potential transport mechanisms. These studies include additional sediment sampling for contaminants in areas within and just outside of the waterways, and analyses of water and suspended sediments from areas near the mouths of waterways (see below, Study Design).

Contaminant Sources

Most of the effort in contaminant source sampling has been directed toward point and runoff sources, with some limited groundwater investigation. Little is known about spills and groundwater contributions of pollutants to the study area, although additional groundwater investigation is underway. The major data gaps in knowledge of contaminant sources are presented in the following list:

- Only two minor NPDES-permitted sources have undergone effluent testing for priority pollutants. Effluent sampling of other minor point sources, prioritized by flow and industrial process, may disclose previously unknown contaminant contributions.

- Flow information on the 423 channels, drains, and ditches identified by Rogers et al. (1983) is inadequate. Dry- and wet-weather flow data on unsampled runoff sources are needed to allow selection of new stations for contaminant sampling.

- There is a large data gap in knowledge of contaminant contributions from runoff sources. Some wet season sampling has been conducted in City Waterway and the Puyallup River, but no full priority pollutant analyses have been conducted on samples collected from the other subareas between September 23 and March 29. Studies proposed by WDOE will fill part of this data gap, but additional stations beyond those proposed by WDOE should be considered for wet season sampling.

- Hylebos, Blair, and City Waterways and Ruston Shoreline have large numbers of unsampled potential runoff sources. City, Blair, and Sitcum Waterways have low spatial coverage index values, and receiving-environment conditions indicate a need for additional runoff source sampling. As pointed out previously, special attention to wet-weather sampling is highly recommended.

- Few contaminant sources in City Waterway and along Ruston Shoreline have been analyzed for organic priority pollutants. Additional testing of organic compounds in point, runoff, and groundwater sources, particularly in City Waterway, is recommended.

- Other than HCBD, no CBD analyses have been conducted on contaminant sources. Where water column or sediment samples show high concentrations of CBDs, the nearby contaminant sources should be tested for CBDs.

- Marine and on-land surface spill quantities and locations are incompletely documented.

- Groundwater flow information for the tideflats area is incomplete. A groundwater contour map of the area is needed to identify flow directions and likely destinations of leached contaminants.

- Additional groundwater and soils investigation of the sites in Table 9 is recommended. Full-scale groundwater studies (e.g., those involving the drilling and sampling of wells) are not warranted at this time; instead, preliminary studies should be conducted to determine the advisability and extent of future investigations.

Contamination and Effects

Most of the available information on media contamination and effects is related to sediment and water quality. Extensive data gaps exist in the areas of pathology, bioaccumulation, and ecology of indigenous communities. The important data gaps are summarized by study type in the following list:

Sediment Quality--

- Limited data are available on contaminant concentrations in surface sediments of Milwaukee, St. Paul, and Middle Waterways, and the Ruston shore. Data on volatile and acid extractable compounds, base neutral organic compounds, and pesticides at locations along the Ruston shore are unavailable.

- Concentrations of volatile organic compounds and acid extractable organic compounds need to be characterized more completely throughout the study area, especially in Blair and City Waterways, and at reference sites.

- Historical data are lacking for characterization of grain-size composition and contamination of sediments. Some limited data are available for deep sediment cores from Blair and Hylebos Waterways.

Water Quality--

- Although spatial coverage of the existing data is suitable for broad characterization of water quality, Sitcum Waterway and the Ruston shore have been sampled inadequately.

- Data on contaminant concentrations in Milwaukee and Middle Waterways are lacking.

- Data on contaminant concentrations in the water column at potential reference sites are limited.

Bioaccumulation--

- Since spatial coverage has been inadequate in past studies, data are lacking for many project subareas. Samples have not been taken from the head to the middle of the waterway at any of the project sites. Only metals have been analyzed in a few organisms in Blair and Sitcum Waterways. No bioaccumulation data are available for Milwaukee, St. Paul, and Middle Waterways.

- Limited data are available for concentrations of acid-extractable, base-neutral, and volatile organic compounds in tissues at all project areas and reference sites. This data gap is most important for Blair, Hylebos, and City Waterways, where the potential for contamination of biota by base-neutral compounds is especially high.

- Information on bioaccumulation by fishes is limited, especially in relation to potential human health effects.

- Because of methodological problems, relatively low concentrations of volatile organic compounds and PNAs in tissues have not been quantified sufficiently.

Pathology--

- Pathological conditions in organisms have been characterized at a total of only seven sites in Blair, City, Hylebos, and Sitcum Waterways. Data gaps exist for other project areas, especially shallow areas (less than 60-ft depth) along the Ruston shore.

- Sample sizes used in previous pathological studies have been inadequate for statistical comparisons of disease prevalence among specific sites. In the past, data from broad areas, e.g., all waterways or all Commencement Bay stations, have been pooled for data analysis.

Benthic Infauna--

- A major data gap exists for benthic macroinvertebrate communities. All quantitative data collected during past studies in the project area are inadequate due to severe methodological limitations.

Bioassay Effects--

Data gaps in bioassay estimation of sediment toxicity fall into the following categories:

- Simple, rapid screening bioassays that provide an accurate and precise estimate of toxic potential need to be developed. Such a screening test would allow selection of samples for detailed, quantitative assessment of toxicity as a function of sediment chemistry.

- Appropriate exposure pathways need to be defined and quantified for estimation of toxicity of the various phase associations of sediment contaminants.

- Assays of suspended particulates and elutriates that give an adequate characterization of toxicity of dredged material have been limited.

- Spatial coverage of Middle, Milwaukee, and St. Paul Waterways has been limited.

- Appropriate reference data are not available.

General--

- Transport pathways and potential causal links have generally not been quantified among: 1) concentrations of conventional or priority pollutants in the sediments or the water column; 2) concentrations of pollutants in tissues; and 3) biological effects.

- Whenever causal links between biological effects and pollutant concentrations in various media have been suggested by correlational analyses, the relative importance of conventional vs. priority pollutants has not been established.

- The bioavailability of contaminants has often not been quantified; e.g., total concentrations of a metal have been determined without partitioning into available ionic forms and nonavailable forms bound to sediment particles.

- Transport pathways for suspended solids and contaminants among project subareas, especially the Puyallup River, Commencement Bay, and individual waterways, are poorly defined.

STUDY DESIGN

The preliminary study design for Phase II of the Commencement Bay project is presented in the following sections. After reviews by WDOE, EPA, the Brown and Caldwell/EVS team, and the Technical Oversight Committee, this preliminary study design will be finalized. Each of the study design sections includes: 1) a list of study objectives; 2) an overview of the study design component, giving the conceptual approach, sample types, and parameters; 3) sampling methods; 4) sample processing; and 5) lab analyses. Refer to the Quality Assurance Program Plan for details of sample handling, analytical chemistry, and QA/QC procedures.

GENERAL APPROACH

The general procedure used in designing studies was based on input from the decision criteria task and a review of existing data (see Figure 1 above, Data Evaluation section). The existing data to be entered into the project data base and data expected to be available from ongoing studies were considered in developing the study design recommended below. These new studies will fill major data gaps identified in the previous section and provide data input to the decision criteria. Thus, the choice of parameters, station locations, and conceptual approach for each recommended study component is based on: 1) the existing data gaps, 2) data needs for development of final decision criteria, and 3) known spatial and temporal characteristics of pollutant sources, contamination of various media, and biological effects.

Study Types and Program Integration

The components of the recommended study design are shown in Figure 21. Refer to the Decision Criteria Report for the rationale behind the choice of these studies and their relationships to one another.

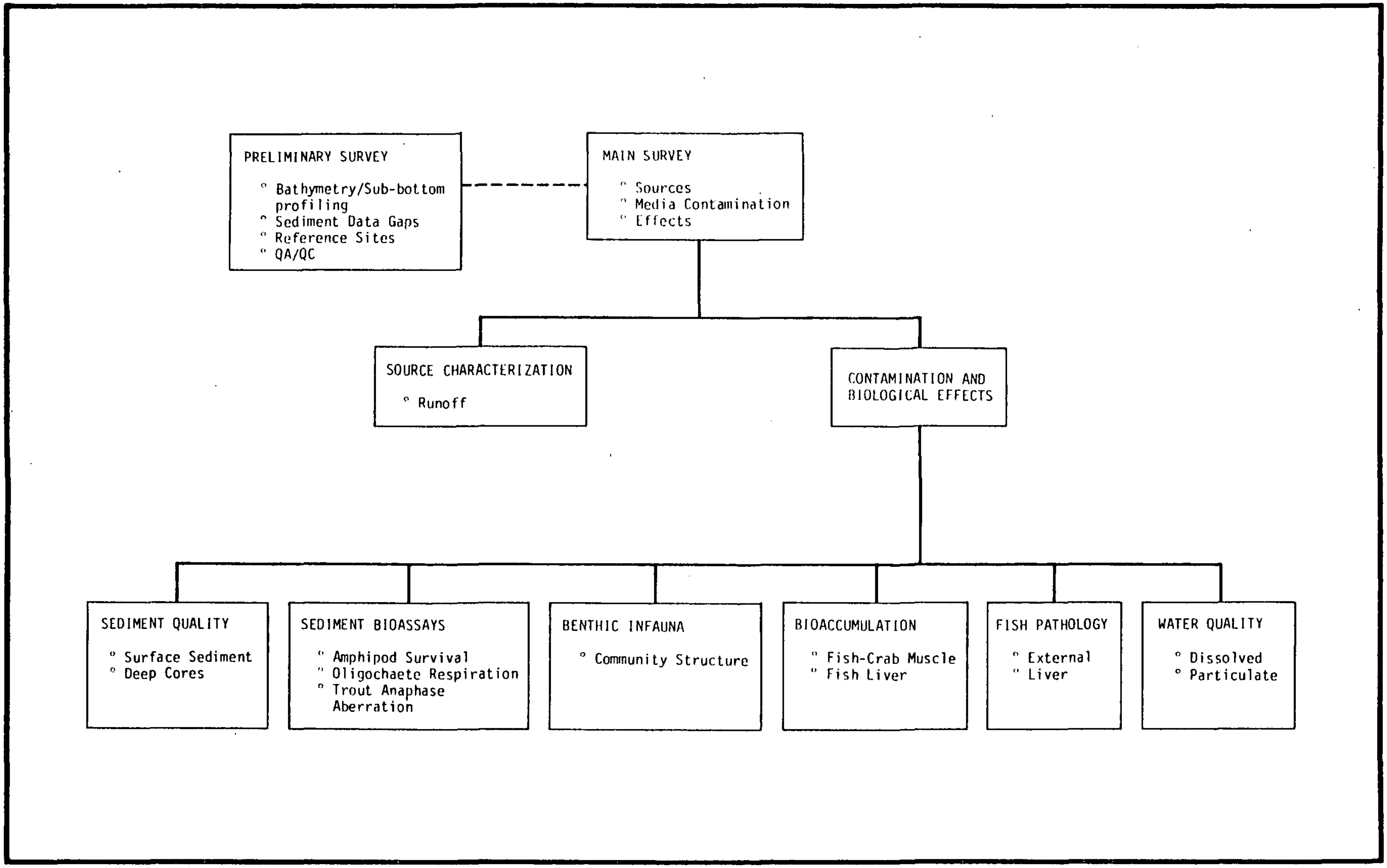


Figure 21. Components of recommended study design.

Each of the studies is intended to meet one or more of the objectives of the EPA/WDOE Cooperative Agreement. Specific objectives of each study component are provided in the introduction to each study design section.

Each individual component of the recommended study is integrated into a coherent, overall plan for achieving the goals of the project. Integration of the studies should occur in three ways: 1) development of a detailed, comprehensive field plan incorporating cruise logistics, sampling methods, and QA/QC procedures in accordance with the QA/QC Program Plan; 2) establishment of relationships among data from different study components during the data analysis phase; and 3) development of final decision criteria. Integration of field tasks and study results is accomplished by establishing common sampling sites, sampling methods, and sampling times for related disciplines (e.g., sediment subsamples for contaminant analysis, conventional parameters, and bioassays are taken from the benthic infaunal samples). Integration of the studies is illustrated in more detail in the individual sampling plans provided in subsequent sections and in the Decision Criteria Report.

Proper timing of the individual studies is important to ensure completion of the project on schedule, efficiency of cruise resources, and collection of appropriate data. The general timing of the field work is outlined below:

- January - Preliminary Survey
- February or early March - Surface Sediment/Infauna Survey
  - Bioassays
- March to early May - Water Quality (during high flow Puyallup River)
  - Runoff Source Survey
- May - Deep Core Survey
- June - Bioaccumulation
  - Pathology

- July - Water Quality
  (during low flow Puyallup River)

This schedule will allow adequate time for sample processing, data analysis, and report preparation.

The rationale for a preliminary cruise and general cruise procedures are provided in the next section. It is recommended that the preliminary survey be conducted in early January to ensure an early start on the project. In this way, results of the initial survey would be available for finalization of station locations and methods for the main benthic survey in February or early March. The benthic survey should be conducted at this time for two reasons. First, early analysis of surface sediment samples will provide additional data for finalization of the deep core survey. Benthic infauna should be sampled as early as possible in spring, so that mostly adults of the stable, overwintering communities are present. By late spring, many unidentifiable juveniles will be present in the benthic samples, complicating the sorting and taxonomic processes. By May, results of the main surface sediment survey should be available, and the deep cores could be collected during a cruise dedicated to this purpose. Sampling of water quality stations at flood tide and high flow of the Puyallup River is anticipated to occur during the period of March to May. A separate cruise during late June is recommended for sampling of crab and fish tissue for analysis of contaminant concentrations and pathological analyses. Sampling as late as possible during the summer season, when migrant English sole have had substantial time for feeding and residency in the waterways is desirable. However, the study plan calls for analysis of pathology before tissue contaminants are analyzed (see below, Bioaccumulation and Pathology). Since approximately 2-3 months will be required for the pathological study, fish trawls must be taken by early June to ensure adequate time for chemical analyses of tissue and data processing. Finally, a second period of water sampling is specified during ebb tide, low flow of the Puyallup River. It is recommended that this sampling be conducted during the latter half of July.

Preliminary Survey

The preliminary survey is a key component of the overall study plan. The incorporation of a preliminary survey into the study design allows:

- Collection of bathymetric and sub-bottom profile data for the waterways, which would be valuable in positioning stations (e.g., trawl sites) for the main survey

- Confirmation of data from previous studies, especially in areas with little data or conflicting data on sediment contamination

- Collection of sediment quality data from project subareas that have not been sampled previously

- Confirmation of potential reference sites and final selection of specific sampling locations

- Initial QA/QC analyses, standardization of general cruise protocol, and verification of field sampling methods.

Final prioritization of subareas and final selection of sampling stations for the main study are dependent on the elimination of data gaps through information collected in the preliminary survey. The preliminary survey will allow a better definition of the spatial extent of known contaminated areas, and ensure that no "hot spots" exist in subareas that have not been sampled previously. If new contaminated areas are found during the preliminary survey, they should be considered along with other sites for detailed sampling coverage during the main study. Ranking of any new sites according to the preliminary decision criteria would then refine the sampling effort for the main survey.

Cruise Procedures--

Standard methods of operation should be developed as part of a cruise plan, incorporating QA/QC procedures in accordance with the Quality Assurance Program Plan for this project. The standard cruise procedures should be tested operationally during the preliminary survey. Special precautions should be taken to prevent contamination of samples during collection and initial processing aboard the vessel. Cleaning of samples, working areas, and instruments before collection of each sample to be used for chemical analyses is essential. Work areas of the ship should be arranged so as to avoid contamination of samples by engine exhaust, oil, and other interfering substances. Details of QA/QC procedures are provided in the Quality Assurance Program Plan.

Station Location Methods--

Because of the many sources and documented spatial heterogeneity of contamination in the waterways system, precise positioning of sampling stations is essential. However, standard electronic methods of navigation (e.g., Loran C and Mini-Ranger) are unreliable in the waterways due to landform distortion of signals. Also, the positioning of numerous stations in such narrow channels would require a large number of shore-based transmitters. It is recommended that station locations be determined previously by line-of-site fixes on stationary shoreline-features. Photographic records of alignments and ranges should also be made. Station positioning methods should be accurate enough to ensure definition of locations within an area defined by a 30-40 ft radius. Station location methods should be verified during the preliminary survey, and standardized procedures should then be used throughout the project.

Semi-permanent station location markers should be set up during the preliminary survey (e.g., shore markers set in concrete to avoid vandalism or underwater transmitters attached to above-bottom buoys). For each survey, a surface-buoy should be anchored near the bow of the vessel and used as a temporary station marker. The boat should be held in position by reference to the buoy and shore-object fixes. Station locations should be verified just before each sample is taken.

Reference Areas--

One primary objective of the preliminary survey is to confirm the suitability of the candidate reference sites, and to select final reference station locations. Muddy and fine-sandy habitats in both Carr Inlet and Quartermaster Harbor are recommended as reference areas (i.e., total of 4 reference stations). Selection of these sites as reference areas is justified in a later section (see below, Contamination and Effects, General Approach). Although true control sites for the Commencement Bay waterways are not available, sampling stations at reference areas should be located in habitats whose characteristics match those of the waterways as closely as possible. Choice of station locations should be based on a qualitative or semi-quantitative examination of the following parameters at a minimum of three sites at each of the reference areas: 1) water depth (approximately 30 ft); 2) dissolved oxygen and salinity of bottom waters; 3) current speed; 4) grain size composition and organic content of the sediments; and 5) presence of at least a moderately abundant English sole population (Carr Inlet only). The muddy habitats should have sediments with a high organic content, whereas sandy sediments should be relatively low in organic carbon to provide a range of reference conditions. Each reference station should be selected to reflect average conditions at either muddy-bottom or sandy-bottom sites in the waterways. The sampling methods used during the preliminary survey should be the same as those specified for individual studies below (e.g., otter trawl for English sole). However, it may be desirable to compare performance of different sediment samplers (i.e., van Veen grab vs. box corer; see below, Contamination and Effects, Sediment Quality).

When sampling stations have been selected, the following parameters should be measured: 1) vertical profile of salinity, temperature, dissolved oxygen, and suspended solids; 2) water depth; and 3) sediment parameters as specified in the description of the sediment quality survey. Samples should be processed and data analyzed before finalization of the sampling plan for the main survey.

PHYSICAL PROCESSES

The objective of the recommended physical processes study is to define the bathymetry, surficial features, and vertical structure of sediments in the waterways. The purpose of collecting bathymetric data is to confirm the water depths recorded on existing charts and to serve as a control for the other concurrently-collected geophysical data.

A side scan sonar survey of each waterway is recommended to provide a detailed record of surficial details of the bottom of the dredged channels. The record will show features extending above the bottom, such as the chlorine cylinders found in Blair Waterway, and other debris which may foul sampling nets or present a hazard to dredging.

Subbottom profiling is recommended to determine the vertical structure of the waterway's sediment column. The profiling record will reveal the depth of accumulation of potentially contaminated sediments over the original deltaic sediment surface. This information will be of importance to planning the location and depth of deep-core sampling and in planning any dredging needed for remedial action.

Study Design

A 3.5 kH2 subbottom profiling system is recommended so that 3-5 m of penetration can be achieved. It should be noted that subbottom profiling will probably not be possible in water depths less than 3-4 m because of acoustic "ringing." Surveys in the shallow waterways should be timed as much as possible around high slack tide. A 500 kH2 side scan sonar system should be used to achieve maximum resolution.

Simultaneous recording of bathymetric, side scan, and subbottom data is recommended. A combined 500kH2 side scan/3.5 kH2 subbottom profiling system similar to that made by Klein Associates, Inc. is suggested. Three equally-spaced transects should be made in each waterway (but not in the Puyallup River) from the head to the mouth of the waterway. The survey should extend into shallow water to the minimum depth at which subbottom profile and side scan sonar records can no longer be obtained. Reasonable effort should be made to extend the survey as far as possible into shallow water by timing the survey around high slack tide.

Five cross survey lines (cross ties) should be surveyed in each waterway. The cross ties should be located in areas where the subbottom profile record indicates maximum deposition of potentially contaminated sediments.

Additional lines should be surveyed along the Tacoma shoreline at the three locations described later in this report for trawl sampling. These locations are in approximately 9 m (30 ft) of water, and are adjacent to Old Tacoma, the ASARCO smelter, and Point Defiance Park. No cross ties are needed at these three sites.

Range/azimuth positioning is adequate for this survey. Every effort should be made to maintain a constant speed of the survey vessel and obtain a position every 150 m (500 ft).

Survey data should be reduced to provide a map of the survey track, an isopact map showing the depth through the sediment column to undisturbed deltaic sediments, and a map of each waterway noting any potential hazards to trawl sampling or dredging. A profile drawing showing the vertical structure of the sediment column at the survey transects along the Tacoma shoreline should be prepared instead of an isopact map.

CONTAMINANT SOURCES

Tasks 3 and 4 of the U.S. EPA/WDOE Commencement Bay Cooperative Agreement provide no funding for the monitoring of NPDES-permitted dischargers or for the drilling and sampling of groundwater wells. Therefore, the contaminant source study recommended here specifies sampling only of runoff sources. This study is designed to provide additional data on the mass loadings of toxic contaminants to the project area. In particular, flow rates and contaminant concentrations measured during wet-season storm events are needed to adequately characterize contaminant mass loadings. Suspended solids sampling is also recommended to provide additional data on the transport of contaminants.

General Study Design

Sampling of major drains and ditches during high winter and low summer flow conditions will provide information on the minimum and maximum expected mass loadings of contaminants to the project area waters. Winter conditions are expected to cause the largest mass loadings of pollutants for two reasons. First, high groundwater levels flush subsurface contaminants from soils, carrying pollutants until intercepted by drains or waterways. Second, contaminants deposited on the ground surface are transported by large amounts of surface runoff and interflow to drains and ditches. Data from existing studies in Commencement Bay consistently have shown higher contaminant mass loadings during periods of high runoff. Conversely, lower mass loadings are evident during low flows, even though contaminant concentrations may be higher.

Based on knowledge of past contaminant contributions and drainage area, six stations are included in the study design. Sampling is also needed at 5-10 additional stations prioritized by wet-weather flow. Prior to initiation of contaminant sampling, a preliminary flow study must be conducted to select runoff sites needing investigation. Those sites with the greatest wet-weather flow can be identified and tested for contaminants.

In addition to the initial flow survey, continuous gaging of flows in Wapato and Hylebos Creeks is recommended. The large watersheds and known or suspected contaminants of these streams point to the need for better flow information. The streams should be gaged for a minimum of 1 year, with monthly current-meter measurements to determine the stage-discharge relation. Additional details for selection of station sites, use of current meters, and determination of the stage-discharge relation can be found in Linsley et al. (1975).

The parameters to be sampled include all of the priority pollutants and total suspended solids (TSS). Since previous sampling efforts have not been conducted during wet weather, elimination of some contaminant groups is not justified without additional information on the nature of contaminant sources, particularly subsurface deposits subject to leaching. TSS sampling will provide additional information on the transport and fate of contaminants in the waterways.

Station Locations

Four waterways (Hylebos, Blair, Sitcum, and City) have been selected for additional runoff sampling. Three of these waterways (Hylebos, Blair, and City) have large watersheds and are likely to receive considerable quantities of pollutants from runoff. The fourth waterway (Sitcum) has a small drainage area and few drains, but has not been sampled in winter. High contaminant concentrations in sediments have also been observed in Blair Waterway.

Three studies currently being conducted by WDOE have as an objective the collection of runoff source data (Krull 1983). These investigations provide for the monitoring of six major drains, identification of metals sources to Sitcum Waterway sediments, and sampling of metals and organic compounds in City Waterway sources. Stations have been identified only for the first study; when stations are designated for the other two studies it may be necessary to modify the program design described here to avoid duplication of effort. Runoff sites not identified in the first ongoing WDOE study, but selected for sampling here, are the following:

- The drains opposite Lincoln Avenue in Hylebos Waterway
- The north Lincoln Avenue drain in Blair Waterway
- The drain at the west corner of the Blair Turning Basin
- Wapato Creek

- The drain at the head of Wheeler-Osgood Waterway

- The 15th Street drain to City Waterway.

These drains have significant drainage basins or have demonstrated significant pollutant mass loadings in previous studies. None of these 6 sites has been sampled during wet season flows. Since these sites have been previously sampled during the dry season, collection of wet-weather samples should be sufficient.

Additional runoff sampling stations will be selected from those drains exhibiting high flows during winter storm events. Visual observation of the drains in Blair, Hylebos, City, and Sitcum Waterways may provide sufficient basis if a group of drains clearly have high flows in comparison to the rest. If it proves difficult to select 5-10 drains by inspection, it will be necessary to measure flows with weirs, flumes, or current meters to provide a basis for station selection.

Sampling Methods, Processing, and Analyses

Composite samples are necessary to measure the mass loading throughout the storm event. At the six major drains specified previously, samples should be collected by an automatic sampler, composited in proportion to flow, and the flow rate measured throughout the sample collection period. Beginning and ending times must be noted, and rainfall data for the same time period recorded. If flow-proportional sampling is not feasible, automatic sampling at fixed time intervals is an alternative. Sample collection at 30-min intervals for the duration of the storm event, or a minimum of 24 h, is recommended. Because contaminant concentrations are highest during the beginning of the storm event, sampling of the initial flow is critical. A grab sample of the initial flow should also be collected and analyzed for the volatile organic priority pollutants.

Composite sampling at the stations selected as a result of the flow survey is not recommended at this time. Grab samples and accompanying instantaneous flow measurements will be sufficient to estimate mass loadings from these sources.

Sample processing and analysis should follow the procedures specified below in the water quality study design.

CONTAMINATION AND EFFECTS

Studies recommended for the main surveys are outlined in the following sections. An overview of the conceptual approach to contamination and effects studies is given in the next section.

Conceptual Overview

Discrimination of spatial patterns in contaminant distributions and biological responses is a major objective of this project. Several approaches to spatial analysis are recommended: 1) assessment of contamination/response at individual stations for detection of "hot spots"; 2) gradient analysis; 3) comparisons of averages for waterways and subareas as input to the priority ranking procedure; and 4) comparisons of individual stations, waterway averages, and subarea averages with data from external reference sites. Approaches 1), 3), and 4) above are discussed further in this section. Gradient analysis is discussed in detail later in relation to the main benthic survey.

Each of these approaches to spatial analysis will be important for assessing the heterogeneous distribution of contamination in the project area. This information can also be used to determine the extent of contamination associated with individual sources. If major sites of contamination are found beyond the influence of all known sources, then other causes must be investigated (e.g., historical contamination, unidentified local source, or undefined transport process).

Existing data are generally oriented toward characterization of known pollutant sources and areas of contamination associated with these sources. Although this kind of data is of prime importance in the Superfund project, it is also desirable to compare contamination levels and effects at known "problem areas" with those at less contaminated sites within the project area, and at reference sites in other portions of Puget Sound. Comparisons of potential "problem" and "no-problem" subareas and comparisons among waterways will facilitate development of quantitative links among pollutant inputs, contamination levels, and biological effects. At the same time, comparisons between waterway data and reference data will establish the degree of contamination at a given project (sub)area relative to background levels in Puget Sound. The foregoing relationship will ensure a solid technical basis for development of priority rankings for project sites, final decision criteria, and remedial action.

Two reference areas are suggested for these studies: Quartermaster Harbor and Carr Inlet. The use of two reference areas is desirable partly because environmental data are highly variable and information from two sites will give a more representative picture of background conditions than data from one site alone. Based on existing data, it appears that Carr Inlet may be less contaminated than Quartermaster Harbor. Thus, the latter will serve as an intermediate case between the project area and a more remote reference site. Both recommended reference areas have enclosed, shallow bays comparable in at least their general qualities to portions of the project area. A muddy habitat and a fine-sandy habitat, each about 30-ft in depth, should be sampled at each reference area. The 30-ft depth was chosen because this is about the average depth of many of the Commencement Bay waterways. Sampling of both muddy and sandy habitats will ensure a range of conditions is characterized corresponding to habitats expected in the project area.

It is apparent that no true control site exists for the project area. The waterways may be a unique ecological system. Nevertheless, Carr Inlet and Quartermaster Harbor represent reasonable reference areas. Other sites in Puget Sound were considered as potential reference areas, e.g., Case Inlet, Nisqually Delta, and Liberty Bay. However, none of these other sites offered a combination of the right salinity, sediment conditions, bathymetry, and biotic composition and proximity to the study area. Further justification for choice of the recommended reference sites is provided in the sections below (e.g., see Bioaccumulation and Pathology). Data from an ongoing study of Puget Sound reference areas by EPA and Battelle should be consulted, as soon as it becomes available. Confirmation of the suitability of Carr Inlet and Quartermaster Harbor as reference areas is necessary during the preliminary cruise. Moreover, final selection of exact sampling locations should be made at that time.

Based on existing information, we have designated potential "problem" subareas and potential "no-problem" subareas within several waterways (Figure 22). These characterizations were made after consideration of bioassay results, location of important pollutant sources, and media contamination data. Note that the designation "no-problem" does not mean that remedial action will not be necessary. This designation only indicates that these sites appear to be less contaminated and produce fewer adverse biological effects than other sites in the study area. Station maps in each of the following sections should be compared with Figure 22 to support the rationale given for station placement in each study plan.

Sediment Quality

The sediment quality study recommended here consists of three components: a preliminary survey, a surface sediment survey, and a deep core survey. The main objectives of these surveys are: to determine the type and extent of contamination in the sediments [Cooperative Agreement (CA) Objectives 1-3, 6]; to determine the physical properties of sediments related to contaminant availability, transport pathways, and engineering aspects of dredging (CA Objectives 7, 8); and to establish relationships between sediment contamination and tissue contamination, and between sediment contamination and biological effects (CA Objective 9). In addition, information generated during the sediment study will be used to develop the final Decision Criteria for prioritization of contaminants and project subareas in terms of threat to human health and the environment (CA Objectives 4, 5).

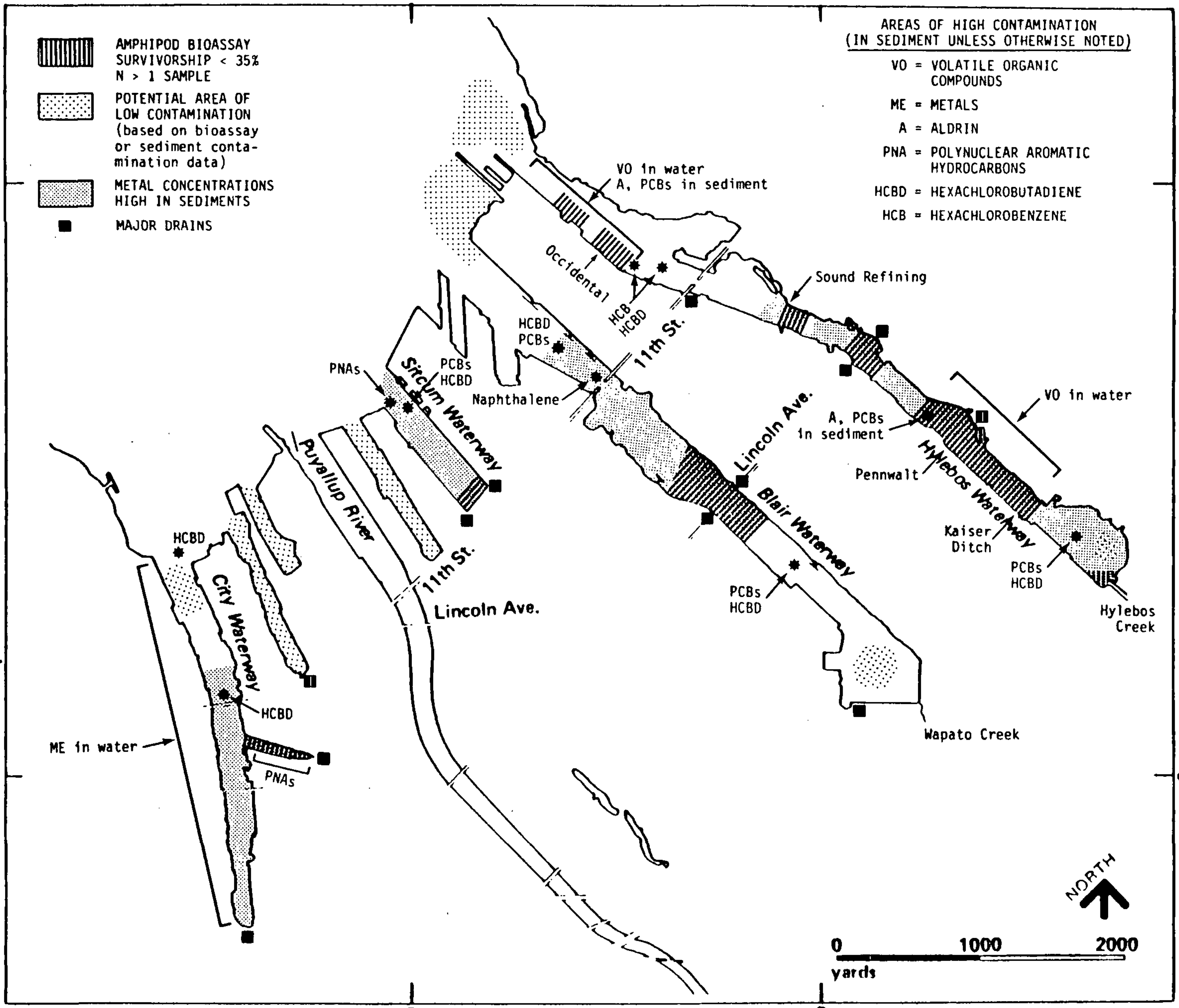


Figure 22. Areas of high contamination and potential areas of low contamination.

General Study Design--

The parameters recommended for the sediment quality surveys include the following:

Priority Pollutants

- Whole sediment concentrations
- Elutriate test (deep core survey only)

Conventional Pollutants

- Sulfide (preliminary and surface sediment survey only)

Ancillary Parameters

- Total organic carbon, hydrogen, and nitrogen content
- Total volatile solids (preliminary and surface sediment surveys only)
- Percent solids
- Grain size analysis
- Unified soils classification (deep core survey only)

The chemical analyses for priority pollutants should be comprehensive during the preliminary survey, but "dedicated analyses" may be performed as part of the main study. Based on existing data and the results of the preliminary survey, a list of important contaminants, which will be analyzed for during the main study, should be finalized and submitted to WDOE for review. All contaminant groups (metals, pesticides, PCBs, etc.) except volatile organic compounds should be analyzed for in all sediment samples during the main study. Sediments are not an important sink for volatile organic compounds in general. However, several selected sites near potential sources should be examined for the presence of volatile contaminants as part of the main survey, i.e.: midchannel stations off Pennwalt and Occidental Chemical in Hylebos Waterway; and one station at the head and one at the mouth of City Waterway.

In the preliminary survey and the surface sediment survey, only the top 2-cm layer of each sediment sample is to be collected and analyzed. In the study area, the surface sediment layer is the only biologically-active zone of the sediments. Hence, contaminant concentrations in surface sediments are of most interest from the standpoint of relating contamination to biological uptake, bioaccumulation, and effects. At most undisturbed sites, the surface sediments are expected to contain the highest concentrations of contaminants (e.g., Riley et al., 1981). However, at previously dredged or filled sites, disturbance of the sediments may modify the expected pattern, producing subsurface peaks in contamination. Historical inputs of pollutants in areas where source loading is reduced at present could also produce subsurface peaks.

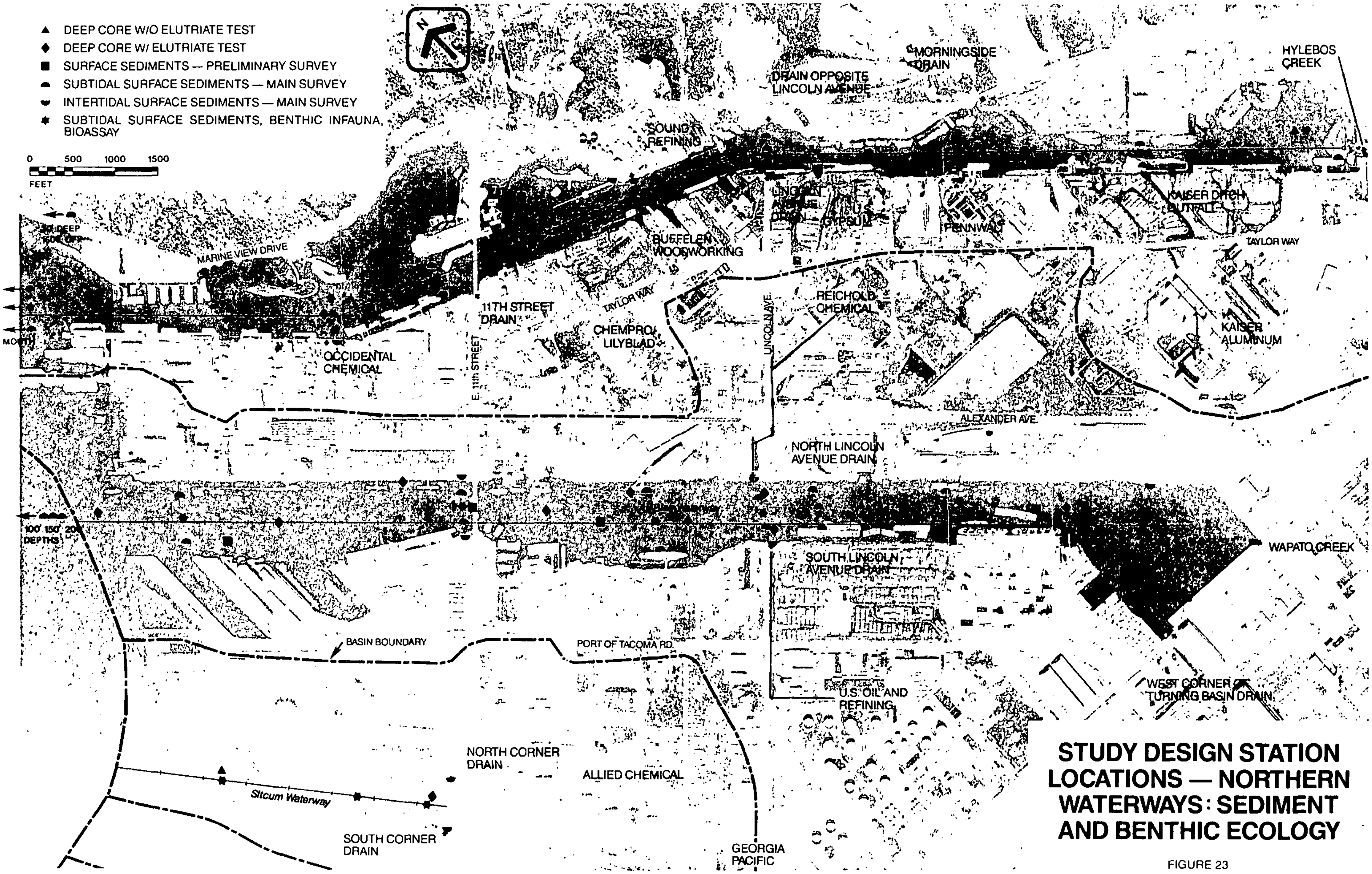
The preliminary survey and surface sediment survey provide information on the areal distribution of contamination, whereas the deep core survey imparts a historical perspective by quantifying contaminant concentrations and ancillary parameters in various depth layers of the sediments (0-2 cm and 30.5 cm vertically-composited intervals). Elutriate tests should be performed on deep-core subsamples from selected stations to indicate the potenial for remobilization of contaminants to the water column during uncovering of historical sediments or during placement of dredged sediments at a submarine disposal site. Potential contaminant concentrations in effluents from a confined disposal site for dredge spoils can also be predicted from the results of an elutriate test. Each deep core and vertically-composited subsample should be classified according to the Unified Soil Classification System (Bartos 1977). This system provides a standard format for detailed descriptions of soil texture, consistency, stratification, particle angularity, and other parameters for input to engineering specifications (e.g., dredging techniques, disposal site selection, and placement of dredge spoils).

Ancillary information should be collected for every surface sediment sample, including data on total organic carbon, hydrogen, and nitrogen content, sulfide content, particle size composition (percent gravel, sand, silt, clay), and percent solids. Total organic carbon, hydrogen, and nitrogen content should also be measured in deep core samples. Concentrations of organic contaminants can then be normalized to total organic carbon values of each sediment sample to account for varying ratios of organic to inorganic substances among samples. Hydrogen and nitrogen content data will be useful for interpreting other core information. Data on sulfide content will indicate the potential toxicity of bottom sediments due to conventional pollutants and processes (e.g., deoxygenation of surficial sediments, high BOD, and release of toxic forms of sulfur). Grain size analysis allows effects of toxic substances or conventional pollutants to be distinguished from physical influences of the habitat on benthic infaunal communities.

Station Locations--

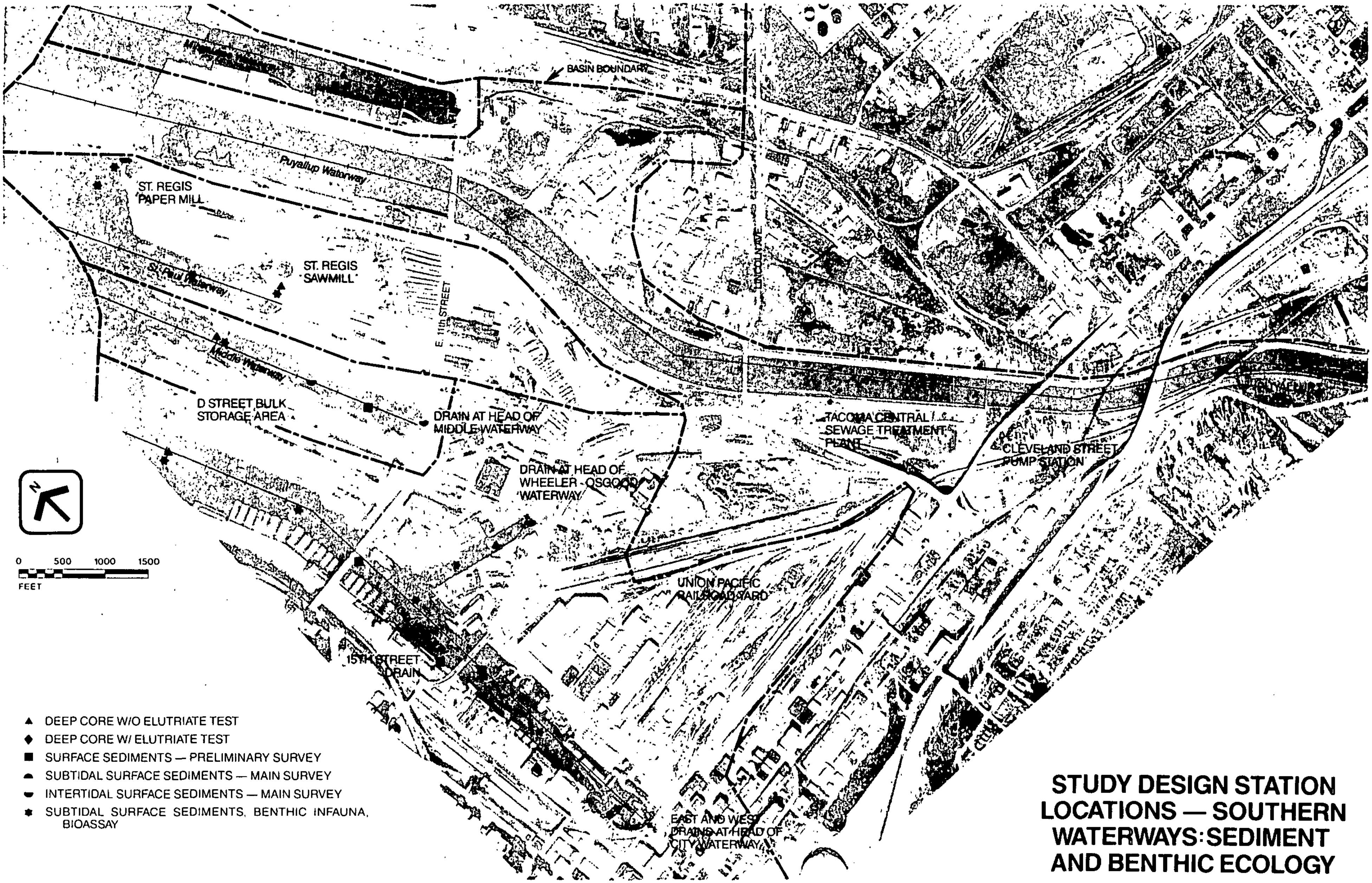
The locations of sampling stations recommended for the sediment and benthic infauna surveys are shown in Figures 23-25.

Preliminary Survey--A total of 19 stations is recommended for the preliminary survey. The stations for the preliminary survey are positioned mainly in project subareas that have not been sampled before. Since Sitcum and St. Paul Waterways have received reasonable spatial coverage in previous studies, and additional sediment samples from these sites are recommended for the main survey, no preliminary survey stations are located in these waterways. Intertidal samples should be taken near two log-storage areas on the northern shore of Hylebos Waterway (northwest of Sound Refining Co.). Another intertidal sample is recommended near a drainage outlet (TPCHD No. 230 in City Waterway) that has not been sampled previously. All other samples recommended for the preliminary survey are subtidal sediments. Three stations are located along Ruston Shore to fill data gaps and to confirm data from previous studies off Old Tacoma. Samples should also be collected from potential sampling sites in fine-sandy and muddy subtidal habitats at both reference areas (total of four reference surface-sediment samples).



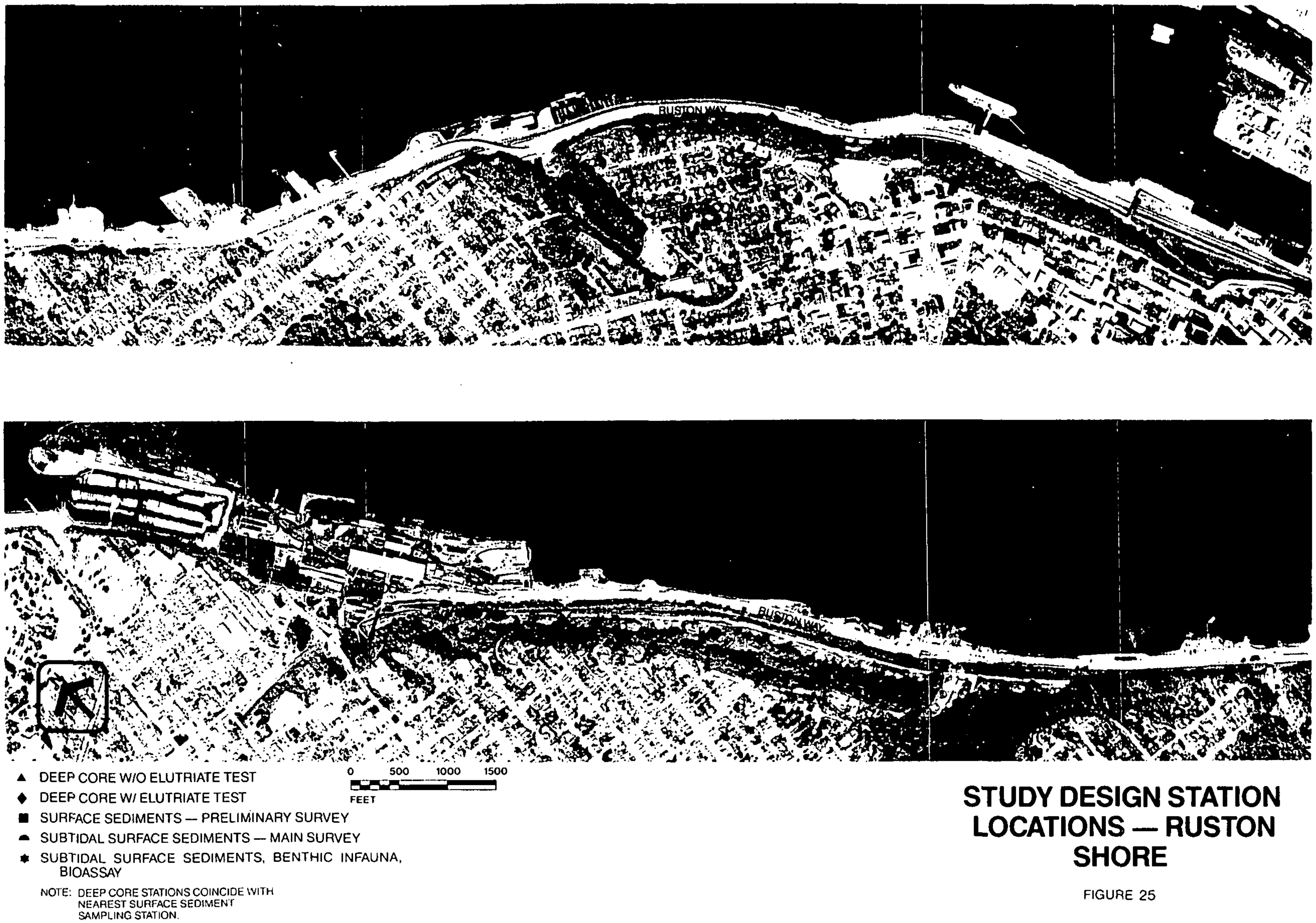
STUDY DESIGN STATION LOCATIONS — NORTHERN WATERWAYS: SEDIMENT AND BENTHIC ECOLOGY

FIGURE 23



STUDY DESIGN STATION LOCATIONS — SOUTHERN WATERWAYS: SEDIMENT AND BENTHIC ECOLOGY

FIGURE 24



STUDY DESIGN STATION LOCATIONS — RUSTON SHORE

FIGURE 25

Main Survey, Surface Sediment--A total of 115 stations are recommended for the main survey. The sampling stations for the main survey were allocated to individual waterways based on consideration of existing data gaps, waterway area, and priority ranking of the waterways in terms of sediment contamination. The majority of stations are located in Hylebos (36 stations), Blair (26 stations), and City (8 stations) Waterways, and along the Ruston Shore (20 stations).

Analysis of spatial patterns of contaminant distributions is a main objective of this study. Stations have been positioned to allow quantitative description of contamination gradients at different scales. First, gradients may exist at the level of an individual waterway (Figure 26). For example, metals in sediments reach their peak near the Lincoln Avenue drains and decline toward each end of Blair Waterway (Figures 22 and 26). Gradients at the scale of a waterway can be longitudinal or transverse. Gradients in contaminant concentrations may also exist at a finer scale around individual point sources. Again, gradients may be longitudinal or transverse in this situation. Although other patterns of contamination are possible (e.g., random or uniform distribution), existing data suggest that some gradients in contaminant concentrations are likely, at least in the heavily contaminated waterways. At the less contaminated sites, spatial coverage of the existing data is not adequate for a preliminary gradient analysis. Theoretically, less contaminated waterways should be more likely to exhibit a random or uniform pattern of contamination than heavily-contaminated waterways.

Gradient analysis provides the framework for testing of hypotheses about spatial patterns regardless of the actual pattern. In the real world, several types of gradients may overlap, obscuring individual source-related contamination patterns. Moreover, we recognize that a pattern of localized hot spots is superimposed on a more general spatial pattern in most of the waterways. Definition of simple, hypothetical spatial patterns as in Figure 26 allows characterization of the actual spatial pattern relative to one or more selected null hypotheses.

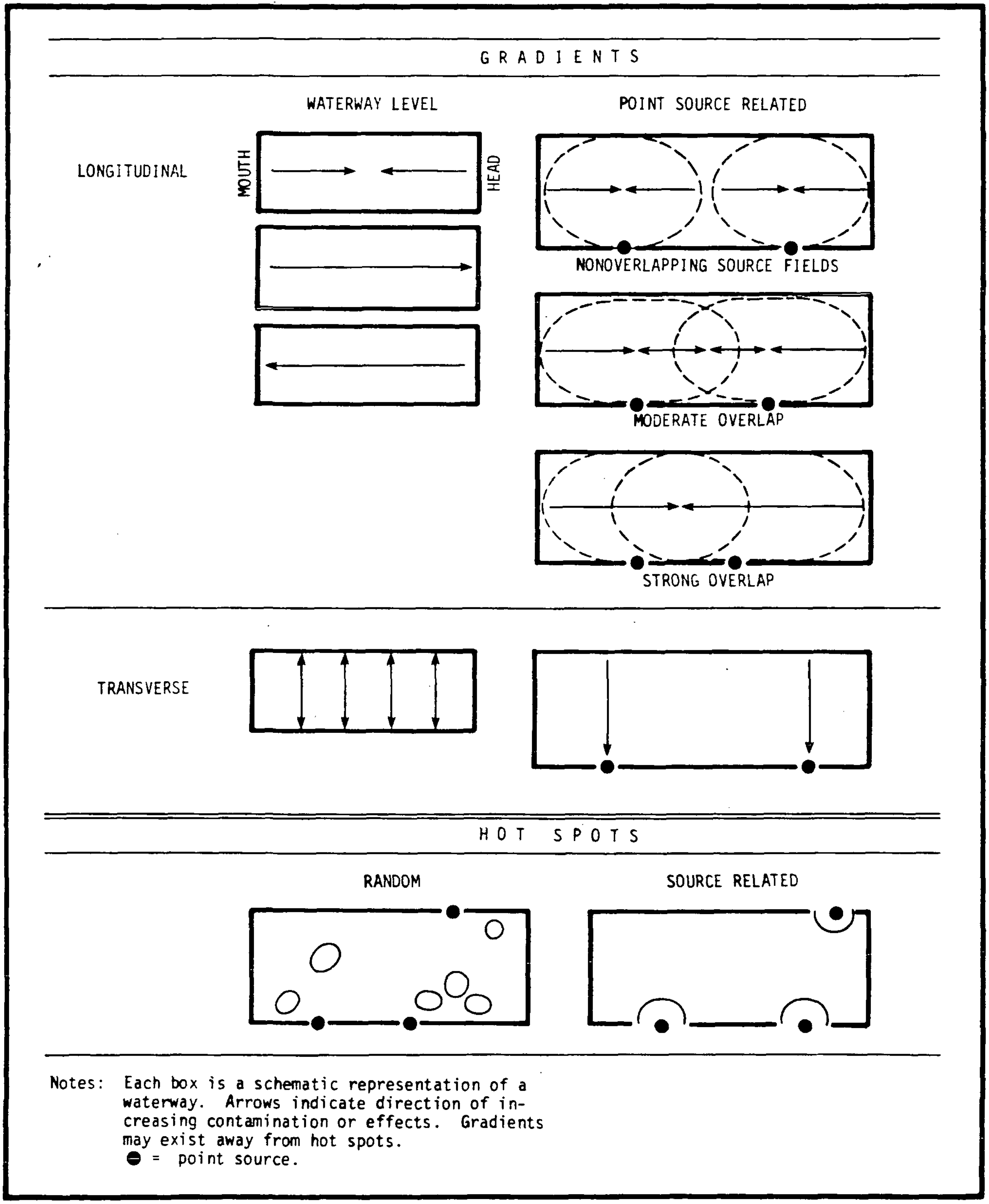


Figure 26. Hypothetical spatial patterns of contamination and effects in Commencement Bay waterways.

The station locations suggested here will allow discrimination among probable spatial patterns of contamination, thereby providing input to subarea priority rankings. The rationale for placement of stations is given below.

Hylebos - 15 stations are located along the midchannel line for assessment of longitudinal gradients. Two additional subtidal stations (north and south of midchannel line) are located at each of the major sources, at an intermediate site (west of 11th St. Bridge), and near the waterway mouth for assessment of transverse gradients. Intertidal stations are located near sources, mainly to confirm historical data. Two additional stations at the head of the waterway are positioned with respect to a possible gradient away from Hylebos Creek.

Blair - The rationale for station placement is similar to that for Hylebos Waterway, but the main suspected sources are the Lincoln Avenue drain, the log sort yard on the south shore, and Wapato Creek. Several transverse transects are placed near Lincoln drain to refine description of gradients in this area of the waterway.

Other Waterways - Several subtidal stations are located in high priority waterways (Sitcum and City) for assessment of longitudinal gradients. Intertidal stations are placed at major drains and corresponding nearby subtidal sites will allow detection of gradients. In less contaminated waterways, the sampling effort is reduced. Sufficient stations were located in Milwaukee Waterway, so this less contaminated site can serve as the primary internal reference site for the waterways system.

Puyallup River - In the sediment quality surveys and other studies, data collection is not recommended for the Puyallup River because: 1) this waterway is relatively clean; 2) comparisons with other waterways are meaningless because of extreme hydrologic and water quality differences between the Puyallup River and each of the other waterways; and 3) the major pollutant source, Tacoma Central STP, will be investigated in a separate study as part of the EPA 301(h) process.

Commencement Bay - Several stations should be located off the mouths of Hylebos and Blair Waterways to confirm historical data that suggest contaminant concentrations drop off rapidly with depth and distance from the waterways.

Ruston Shore - Five stations are located along the Ruston Shore from City Waterway to the ASARCO area, to fill data gaps and assess gradients away from the waterways. Twelve stations have been allocated to the ASARCO area to assess alongshore and onshore-offshore gradients at an upcurrent site and at each of the three discharge areas. Three stations off the northeast shore of Point Defiance Park will provide an assessment of contaminants near a recreational fishing area and a useful comparison with data from the ASARCO site. The ASARCO and Point Defiance stations should be located at 5-ft, 30-ft, and 60-ft depths to assess gradients away from the outfalls.

Reference Areas - Two stations (sandy and muddy habitats) at each of the two reference areas will cover a range of conditions for comparison to the Commencement Bay sites.

Deep Core Survey--A total of 29 stations is recommended for the deep-core sediment survey (Figures 23, 24, and 25). Eleven of these stations are located in Blair Waterway as part of the environmental assessment to be carried out for the Port of Tacoma's waterway dredging project. Other stations are located mainly in heavily contaminated subareas of City and Hylebos Waterways, in representative subareas of each waterway to give a general characterization of the sediments, and at sites scheduled for dredging in the future according to Isakson et al. (1983). One station should be located at each of the ASARCO outfall areas (5-ft depth), since dredging of contaminated sediments may be considered for remedial action at these sites. Two additional deep core stations should be located along the Ruston Shore in areas shown to have contaminated sediments during the surface sediment survey. Elutriate tests are recommended for deep core samples at selected stations in contaminated areas with a high potential for dredging (Figures 23-25).

Sampling Methods and Sample Processing--

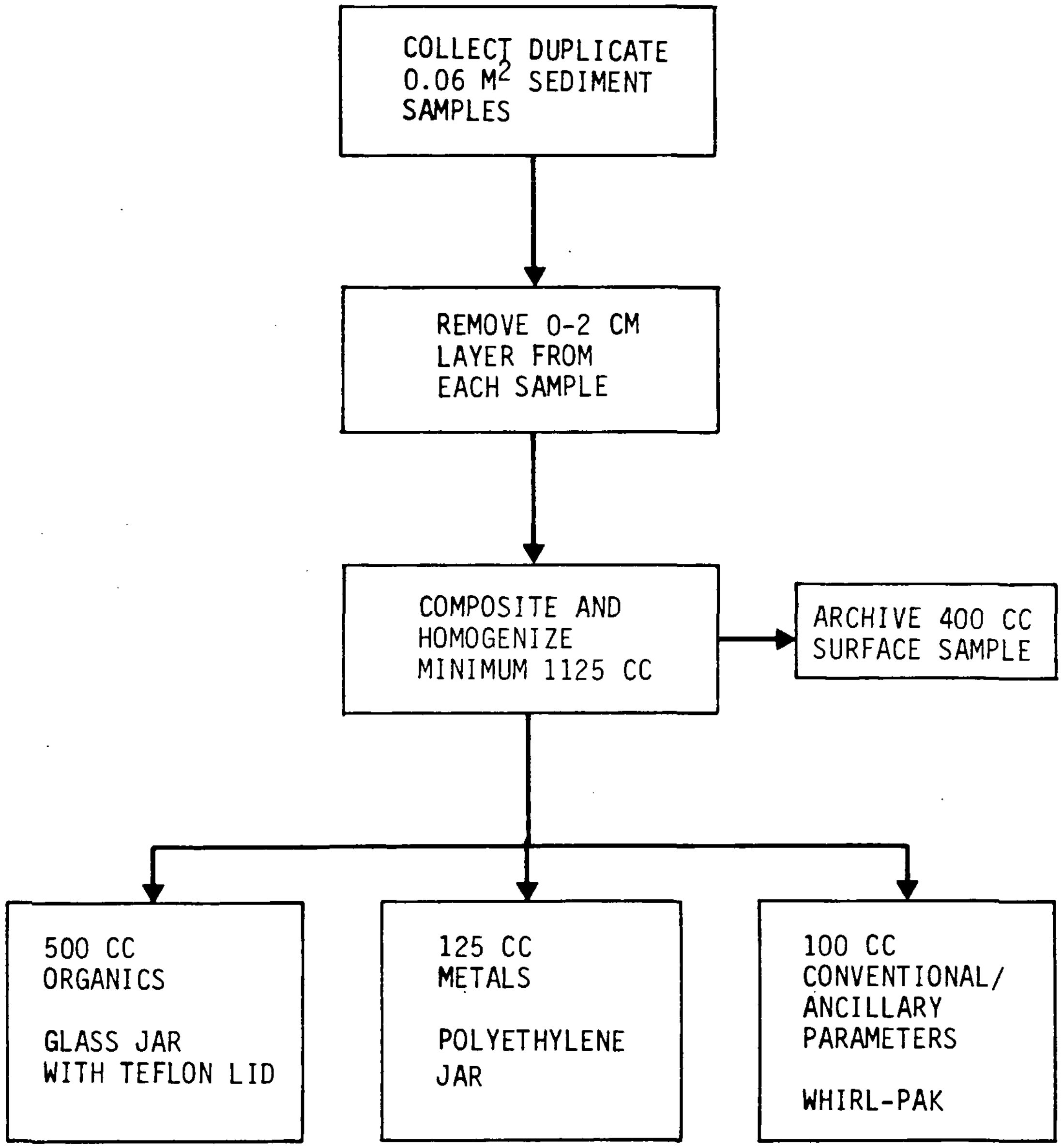
Surface Sediment--A 0.06-m^2 box corer is recommended for collection of subtidal-sediment samples during the preliminary and main surveys. The box corer collects an intact surface layer of sediment and has a high efficiency (i.e., number of acceptable samples collected divided by number of sampling attempts). In contrast, grab samplers often "misfire," or disturb the surface sediment layer as they sample. The only disadvantage of a box corer is its weight. A large sampling vessel is required for operation of a remote box corer. Intertidal and shallow subtidal samples should be collected with a hand-held, lightweight box corer (0.06 m^2).

The van Veen grab sampler has been used extensively in previous benthic surveys of Puget Sound. Since comparability of project data with previous studies is desirable, the box corer could be compared with a 0.06-m^2 chain-rigged van Veen grab during the preliminary survey. The final selection of a sediment sampling device should be justified fully before the main survey.

The collection and treatment scheme for benthic samples is summarized in Figures 27, 28, and 29. At all of the preliminary survey stations and at 65 of the main survey stations, a single grab sample will be adequate (except for QA/QC duplicate samples at selected sites).

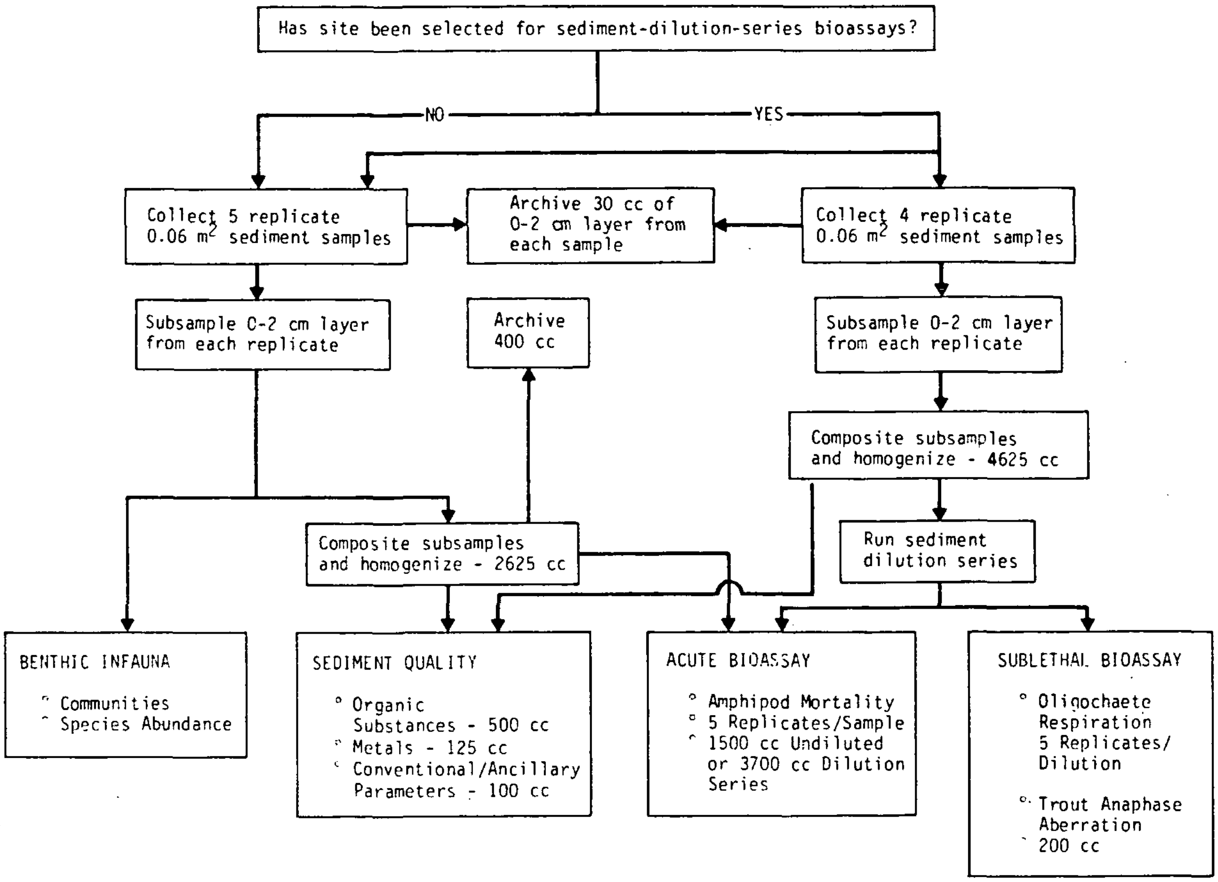
At the remaining 50 stations to be sampled during the main survey, replicate samples will be taken for analysis of benthic infauna and sediment bioassays. A subsample of each replicate grab should be collected, and a composite of the 0-2 cm layers from all subsamples should be analyzed for contaminants and conventional physical-chemical parameters. Additional sediment subsamples (0-2 cm layer) will be required for amphipod bioassays at the same 50 stations. The total amount of material needed in the composited 0-2 cm subsample is estimated as 2,625 cm^3:

- 400-500 cm^3 for analyses of organic chemical (500 cm^3 if volatile organic compounds are being analyzed)



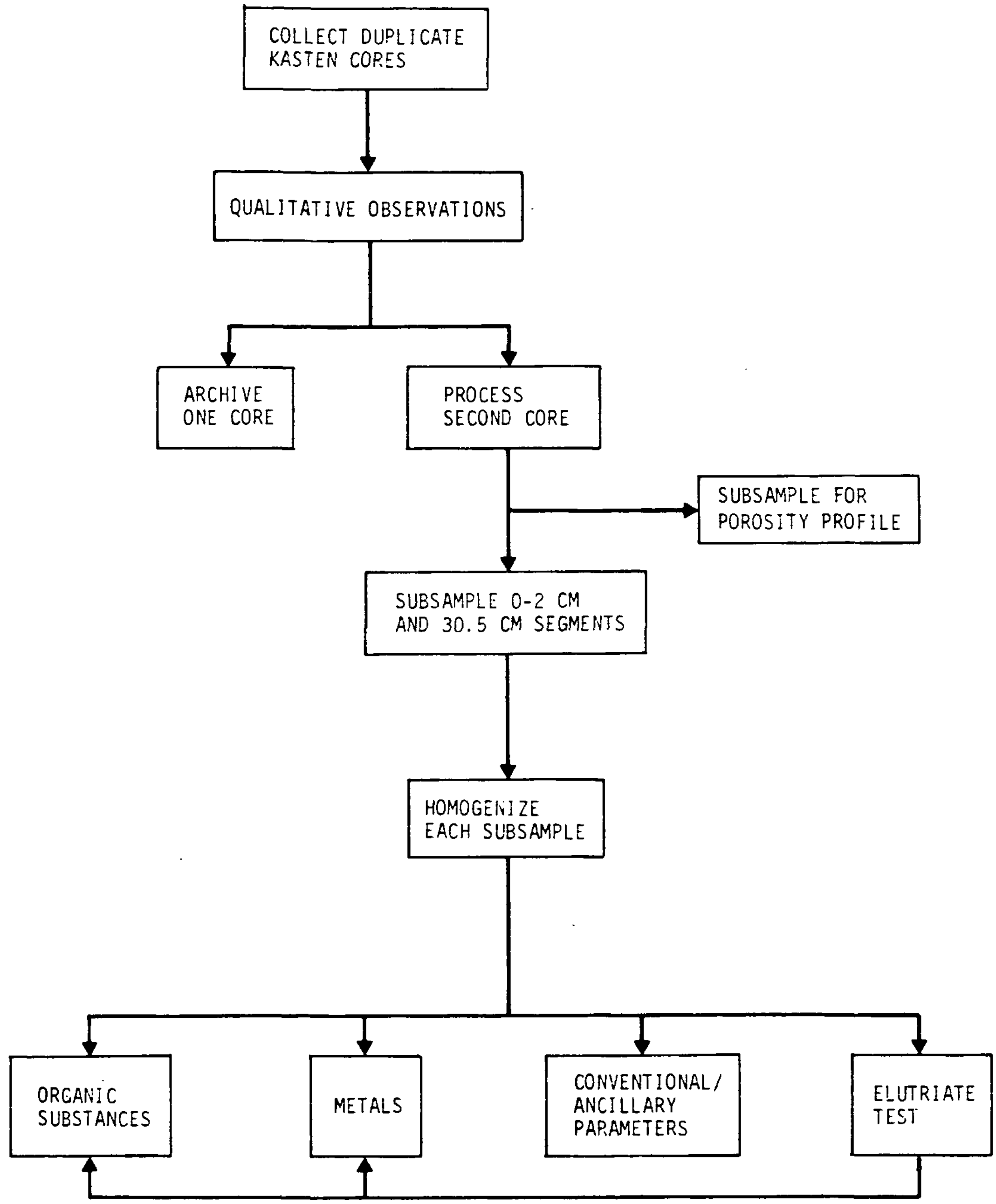
NOTE: Archive samples should be stored frozen for possible future chemical analyses.

Figure 27. Sample processing scheme for sediment quality study - surface sediment.



NOTE: Archive samples should be stored frozen for possible future chemical analysis.

Figure 28. Sample processing scheme for surface sediment, infaunal communities, and bioassays.



NOTE: Archive samples should be stored frozen for possible future chemical analyses. Elutriate test samples should be kept cool but not frozen.

Figure 29. Processing scheme for deep core sediment samples.

- $125\ cm^3$ for analysis of metals
- $1,500\ cm^3$ for bioassays
- $100\ cm^3$ for grain-size analysis and sulfide, and total organic carbon, hydrogen, and nitrogen content analysis
- $400-500\ cm^3$ for archive sample ($500\ cm^3$ if volatile organic compounds are not being analyzed at the station).

To obtain a $2,625\text{-}cm^3$ composite subsample, of the 0-2 cm layer, a total area of about $1,312\ cm^2$ must be collected. It is anticipated that approximately five replicate samples will be required for the benthic community assessment (see below, Benthic Ecology, General Study Design). Thus, about $262\ cm^2$ of the surface sediment layer from each of five replicate samples must be collected. If a greater or lesser number of samples is required for benthic community analysis, the area of the 0-2 cm layer removed from each grab for chemistry and bioassays should be adjusted correspondingly.

Care should be taken to ensure uniform lighting of the grab sample when a subsample is collected, to minimize clumping of mobile organisms due to phototaxis. Subsamples should be taken away from the edges of the grab.

At the five stations where bioassays are recommended for sediment dilution series (see below, Benthic Ecology), three additional samples should be taken for bioassays and chemical analyses (Figure 28). This procedure is necessary because adequate area is not sampled by six replicate cores (or grabs) for analysis of benthic infauna and a sediment dilution-series bioassay. Moreover, the bioassay of undiluted sediments will be replicated by this procedure, allowing an assessment of variation due to sampling and bioassay response.

Subsampling and compositing of subsamples is justified for several reasons. Subsampling provides information on contamination, benthic infaunal communities, and bioassay responses (undiluted sediment) for the same sediment samples. Since average conditions are of interest for the infauna survey, it is desirable to composite subsamples taken for chemistry and bioassays. High costs of chemical analyses prohibit processing of six replicates separately. Assessment of variation in contaminant concentrations at all 50 of the sediment-infauna-bioassay sites is beyond the scope of this project. Nevertheless, some QA/QC samples could be subjected to such an analysis.

Deep Core Survey--Using a Kasten Corer, duplicate deep core samples should be collected near the center of selected contamination zones or other sites with a high priority for dredging (Figure 29). Based on sub-bottom profiling, the depth of penetration of the core should correspond to the level of deltaic sediments. Initial characterization of cores should consist of a qualitative description of color and texture of various horizons. One intact core should then be archived. A porosity profile of the other core should be constructed and interpreted before chemical analyses are done to ensure a good sample was obtained. Porosity determinations should be made at small intervals (e.g., 2 cm) near the surface of the core and at large intervals (e.g., 15 cm) in deeper core segments.

A subsample of the core should be taken at 0-2 cm and analyzed for contaminants to confirm data from surface sediment samples. A vertically-composited subsample should be taken from each 30.5 cm layer. Aliquots of each homogenized subsample should be stored for laboratory analyses as shown in Figure 29. The subsampling scheme described above is intended to provide a broad characterization of historical sediments. The 30.5 cm interval specified for core subsamples reflects the estimated precision of a dredging operation. One pass of the dredge head would remove about 30.5 cm of sediments. The physical-chemical composition of the deep core samples influences the choice of: 1) remedial action alternatives, 2) dredging techniques, 3) depth of sediments to be dredged, 4) handling and treatment methods for dredged materials, 5) disposal sites, and 6) spoils placement techniques. Characteristics of dredging technology dictate that successive layers of about 30-cm depth be removed from a site, and that each 30-cm layer is handled, treated, and discarded as a vertical composite.

Laboratory Analyses--

Laboratory analyses of priority pollutants, sulfide, total organic carbon, hydrogen, and nitrogen, particle size composition, and percent solids should be conducted on all sediment samples. Details of QA/QC procedures and references for analytical methods are specified in the Quality Assurance Program Plan. In addition, it is recommended that a minimum sample size of 100 g be used for analysis of volatile organic compounds (see Data Evaluation, Sediment Quality studies for rationale).

Benthic Ecology

The benthic ecology studies recommended here include several bioassays of sediment contamination and an assessment of benthic infaunal communities. The main objectives of these studies are: to determine the abundance and distribution of biota in the sediments (CA Objective 2); to relate sediment and/or water contamination to biological effects, i.e., acute organism mortality (amphipod bioassays), sublethal effects (oligochaete respiration and trout anaphase aberration bioassays), subcellular effects (anaphase aberration), or community structure of benthic infauna (CA Objective 9); and to prioritize areas, subareas, and contaminants with respect to environmental impacts (CA objectives 4, 5).

The amphipod, oligochaete, and anaphase aberration bioassays will provide a measure of short-term response to contamination levels, whereas, the benthic infaunal assessment indicates the ultimate long-term effects at the community level. In addition, data on benthic fauna will fill a major data gap for the project area. The objective of the bioassays is to provide an index that integrates physical, chemical, and biological aspects of environmental contamination and thereby estimate effects on indigenous organisms. Bioassays also serve as management tools in the sense that they may have predictive utility needed in planning remedial action or in mitigation of further damage to the environment.

General Study Design--

<u>Benthic Infaunal Communities</u>--The parameters recommended for the benthic infaunal study are the following:

- Species abundances
- Total abundance
- Species richness
- Species evenness
- Species composition

Determination of these parameters will allow definition of spatial patterns in biological responses to pollution and estimation of the relative degree of response at each site. Species richness, evenness, and the abundances of indicator species can be used directly to analyze community properties in relation to site characteristics. Using numerical clustering techniques, the entire data set on species abundances can be reduced to an interpretable form, whereby groups of stations are identified on the basis of similarities in their species composition and relative species abundances (e.g., Boesch 1977). Other multivariate techniques (e.g., Discriminant Analysis) may be used to relate station-group membership (defined by infaunal community characteristics) to site characteristics, such as grain size composition, depth, conventional pollutant concentrations, organic carbon content, and priority pollutant concentrations. Discrimination among the potential causes of observed alterations in infaunal communities should address the importance of conventional physical-chemical parameters relative to contamination levels. Comparisons of community characteristics among project areas and subareas will provide input to site ranking for the Decision Criteria. Finally, statistical comparisons of data from each area, subarea, or individual station with reference conditions will establish an unambiguous quantitative basis for describing the presence, magnitude, and spatial extent of biological responses to contamination.

Because of the high degree of spatial and temporal variability in benthic community characteristics, it is necessary to analyze a sufficient number of replicate samples. Based on previous studies in Puget Sound and elsewhere, a minimum of four to six replicate 0.1-m^2 van Veen grabs has been recommended (e.g., Holme and McIntyre 1971; Lie 1968; Malins et al. 1982). A total of five 0.1-m^2 replicate samples is usually adequate for most impact assessment work.

For present purposes, five samples is accepted as a preliminary estimate of the number of replicate 0.06-m^2 samples necessary to characterize benthic communities in the project area and at reference sites. Estimates of the recommended number of replicates should be based on species vs. cumulative sample area curves (or species vs. cumulative number of replicates). For a given sampling device, the larger the total area sampled is, the more precise the results are. Recall that over one-third of the area of each grab sample will be removed for chemical analyses and bioassays. Total sampling area will be reduced correspondingly. However, this undesirable effect is countered by the use of a small grab (0.06 m^2 per grab) relative to most previous studies in Puget Sound (0.1 m^2 per grab). Because most benthic species display an aggregated spatial distribution, smaller sampling units give more accurate and more precise results (Green 1979). Therefore, five replicate samples, each with an area of 338 cm^2 (after removal of sediment for other analyses), will probably be adequate for the present purposes.

To determine the actual number of replicates needed for the benthic survey, a series of eight replicate samples should be collected from one site within each of two waterways (e.g., Hylebos and Sitcum). After processing the samples (see below), individual species should be enumerated. Species-area curves should then be examined to finalize the number of replicate samples for benthic community analyses.

Bioassays--We recommend three bioassays be performed on surface sediment samples taken at each of the 50 stations where benthic infauna will be sampled. In order of priority, the assays are:

- Amphipod bioassay (Rhepoxynius abronius)

- Oligochaete respiration (Monopylephorous cuticulatus)

- Anaphase aberration (rainbow trout gonadal tissue)

These three assays should provide an integrated characterization of sediment contamination at three levels of biological organization: 1) acute lethality of whole organisms; 2) physiological response (metabolism); and 3) subcellular response (genotoxicity).

The amphipod bioassay has been used and modified by several investigators (Swartz et al., 1979, 1982a; Ott et al., 1983; Pierson et al., 1983). For the purposes of this study the basic protocol that should be followed is that of Swartz et al. (1982b). The protocol that should be followed for the oligochaete respiration bioassay is that of Chapman et al. (1982a-c) and his colleagues (Brinkhurst et al., 1982; Chapman and Brinkhurst 1983). Results to date suggest that oligochaete respiration may be sensitive to organic contaminants, while R. abronius may be sensitive to metals (c.f., Scott et al., 1983 and their assessment of copper, cadmium, and arsenic toxicity to the amphipod Ampelisca abdita).

Assays for anaphase aberration of rainbow trout gonadal tissue (RTG-2) should follow the procedures developed by Kocan et al. (1982) and implemented by Chapman et al. (1982c). Both direct acting mutagens and promutagens [e.g., benzo(a)pyrene] are capable of producing significant cytogenetic changes in RTG-2 cells (Kocan et al., 1982). Anaphase aberrations of RTG-2 cells have also proven effective in preliminary characterization of sediment contamination in Commencement Bay (Chapman et al., 1982c).

Five of the 50 infaunal sampling sites have been selected for detailed characterization by performing the three bioassays on a series of five sediment "dilutions" (Figures 23 and 24). The dilutions and various sediment extracts for the three procedures should be performed with appropriate positive and negative controls and in such a fashion that results from the three dose response profiles can be compared (see Decision Criteria Report).

Station Locations--

The locations of sampling stations for benthic infauna and sediment bioassays are shown in Figures 23-25. Note that the locations of sediment bioassays coincide with sampling sites for surface sediment characteristics and benthic infauna. A total of 50 sampling stations is allocated to the benthic ecology study.

The rationale for placement of benthic ecology stations is related to that of the sediment quality studies discussed earlier. In particular, most of the benthic ecology stations within the waterways are positioned midchannel to allow analysis of longitudinal gradients in response to different contamination levels. For example, ten stations are located along a longitudinal transect in Hylebos Wateray, and six stations are located along a longitudinal transect in Blair Waterway. Some midchannel transect-stations are located near major sources, e.g.: Kaiser ditch, the Weyerhauser log sort yard, Pennwalt Chemical Corporation main drain, Lincoln Avenue drain, Sound Refining Company, and Occidental Chemical in Hylebos Waterway; the Lincoln Avenue drain in Blair Waterway; and the north and south drains at the head of Sitcum Waterway. Other midchannel stations are located adjacent to the near-source stations or at points intermediate between source locations to allow definition of areas of influence. Finally, stations at the heads and mouths of Blair and Hylebos Waterways are positioned to allow definition of "boundary conditions." Other waterways have a corresponding number of midchannel transect stations based on their priority ranking. Several stations in Milwaukee Waterway will be useful for comparison with the heavily contaminated waterways.

A complete analysis of transverse gradients in benthic biological responses to point sources is beyond the scope of this program. However, a limited number of stations were designated for analysis of transverse gradients at two of the highest priority sites: Occidental Chemical and Pennwalt Chemical Corporation in Hylebos Waterway.

Nine stations are located along the Ruston shore, including: 1) three stations between City Waterway and the Tacoma North End Sewage Treatment Plant to allow detection of possible gradients downcurrent of the waterways; and 2) three stations at the 5-ft, 30-ft, and 60-ft depths along a transect off the main ASARCO outfall; and 3) three stations at corresponding depths off the northeast shore of Point Defiance Park for comparison with the ASARCO site. Physical habitat characteristics at each of the last three stations should be similar to those of the corresponding stations at the ASARCO site.

Benthic infauna should be sampled and sediment bioassays conducted at each of two habitats (muddy, sandy) at both reference areas. Because of the variability of biological communities in nature and the variation in background sediment contamination among reference areas, use of more than one reference site is desirable.

At all stations, amphipod bioassays should be conducted on undiluted sediments. In addition, a series of sediment-dilution bioassays should be performed at selected sites in the project area: Occidental Chemical and Pennwalt in Hylebos Waterway; Lincoln Avenue drain in Blair Waterway; the head of Sitcum Waterway; and the head of City Waterway. These sites represent the highest priority area based on existing information. The sediment dilution series should be performed using all three bioassays (amphipod acute, oligochaete respiration, and trout anaphase aberration).

Sampling Methods and Field Procedures--

The use of a 0.06 m^2 box corer for the benthic surveys was discussed in a previous section (see Sediment Quality, Sampling Methods). Chemistry and physical properties of the sediments, infaunal communities, and bioassay responses will all be analyzed from the same series of replicate samples at a given station (Figure 28). This ensures that biological responses are statistically related to characteristics of the habitat in which the organisms were actually living at the time of sampling. Bioassays should be conducted using composites of subsamples from all replicate grabs. Since the high cost of chemical analyses limits the measurement of contaminant concentrations in replicate samples to a QA/QC program, chemical analysis of all five replicate grabs is not possible. In this case, it is preferable to perform bioassays on composite sediment samples, although the variance component associated with the initial sampling cannot be assessed in the bioassay response variable.

Benthic Infauna Communities--After a benthic sample is collected and aliquots have been removed for physical-chemical parameters and bioassays, the sample should be washed on a 0.5 mm screen. A mesh of this size ensures that representative population samples of most species are obtained. Filtered seawater should be used to wash the samples. If samples are washed before fixation, a nondestructive technique is preferred; e.g., by dipping and gently vibrating the bottom of the sieve in a tub of seawater (Swartz 1978). An initial screening of the 1.0 mm fraction may be desirable to facilitate the initial sorting process. However, the cost of maintaining separate fractions throughout the taxonomy and data analysis stages may preclude separate processing of two sieve-fractions after the initial sorting is completed.

Samples should be placed in 7 percent $MgCL_2$ for 30 minutes to 1 hour to anesthetize the organisms, and then transferred to 10 percent buffered-formalin. Rose bengal stain can be added to facilitate sorting.

Bioassays--All sediment samples should be taken with a box core and removed from the core as described in the foregoing sections on treatment and processing of sediment samples for chemical characterization and infaunal community analysis. Samples should be placed in a clean plastic bag, and the bag sealed following expulsion of air. Samples should be immediately stored in the dark on ice, transported to the laboratory and refrigerated (4^oC), and then assayed within 5 days of collection. Where more than one box core is needed to perform an assay, as in the case of sediment dilution assays, samples from the individual cores should be processed separately and composited in the laboratory.

Rhepoxynius abronius for the amphipod bioassay should be collected from West Beach, Whidbey Island, transported to the laboratory, and incubated in their native sediments for a week prior to use in an assay. During this period of acclimation, the conditions of temperature and salinity should be controlled, and matched to those encountered by the amphipods in a bioassay (i.e., 15°C, 27 ppt). Oligochaetes (*Monopylephorous cuticulatus*) should be collected from Birch Bay, B.C., and acclimated to laboratory conditions as described above for amphipods. Anaphase aberration bioassays of aqueous sediment extracts should be performed with a continuous cell line of rainbow trout gonadal tissue obtainable from the National Fisheries Research Center, Seattle, WA. Cell cultures should be axenic, and incubated at 18°C as described by Kocan et al. (1982).

Laboratory Procedures--

Benthic Infauna Communities--After at least 24 h in fixative, infaunal samples should be washed on a 0.5 mm sieve and transferred to 70 percent ethanol or 40 percent isopropyl alcohol. Using a dissecting microscope, organisms should be separated from the sediment and sorted to major taxonomic categories (e.g., Polychaeta, Oligochaeta, Pelecypoda, Gastropoda, Amphipoda, Isopoda). Specimens from a given sample and taxonomic group should be maintained in a separate vial. All benthic organisms should be identified to species (Oligochaeta, Polychaeta, Mollusca, Crustacea) if possible, or lowest practical taxon (other taxa).

Details of procedures for identification and enumeration of specimens are given by Holme and McIntyre (1971) and Swartz (1978). QA/QC procedures should follow recommendations of these authors and the Quality Assurance Program Plan for this project. A reference collection of species identified during the study should be compiled and archived.

Bioassays--Amphipod bioassays should be performed under controlled laboratory conditions of temperature (15°C), salinity (27 ppt), and lighting (24-h continuous illumination). Five replicate assays should be conducted in 1-l beakers containing 2-cm (ca., 250 g) of test sediment. Composite sediment samples should be mechanically mixed by gentle rotation as described by Chapman et al. (1982a, 1983a). Pore water should be carried along at each step of sample preparation and included in the final assay of bulk sediments. Once sediment samples are placed in the beakers, 750 ml of filtered seawater (1 um, nominal filter diameter) should be layered onto the sediments and the resultant suspended particulate matter allowed to settle. Twenty amphipods should then be added to each replicate beaker and the water overlying the sediments agitated by gentle bubbling with scrubbed (oil-free), water-saturated air. Survivorship of amphipods should be determined following 10-day exposure to the test sediments. At this time, moribund animals should be identified in a separate assay of burial response (Swartz et al., 1982b). Appropriate positive and negative controls examining response of the amphipods to clean and spiked sediments should be performed in addition to assays of sediment samples from Commencement Bay. Both organic and inorganic contaminants should be used in separate series of control experiments. These same procedures apply to the sediment dilution assays needed for detailed characterization of additional samples taken at five sites. Suggested dilutions of test sediment with reference or control sediment are:

- 100 percent test sediment
- 75 percent test sediment
- 50 percent test sediment
- 25 percent test sediment
- 10 percent test sediment.

An additional 4,000 ml of sediment from each of the five sites will be needed to perform each dilution bioassay. As with the single sample bioassays, appropriate positive and negative control experiments should be performed using clean and spiked sediments.

Details for the protocol of the oligochaete respiration bioassay are described by Chapman et al. (1982a). Sample preparation for this assay is significantly different from that for the amphipod bioassay. Previously, weak aqueous extracts were made by agitating sediment samples in clean seawater (20 g/l solution), and removing the particulate fraction as well as most bacteria by settling and centrifugation. For the sake of comparability with the amphipod bioassay, we suggest that the aqueous extract be prepared from a more concentrated slurry of 20 g bulk sediment/100 ml clean, filtered seawater (0.22 um nominal pore diameter). We furthermore recommend that all aqueous extracts of sediments be prepared immediately upon returning sediment samples to the laboratory, and stored frozen until assayed. In the sediment dilution assays, the five experimental dilutions should be prepared with similarly extracted sediment from the control or reference site. Again, appropriate positive and negative controls should be performed using both organic and inorganic substances that are known to affect respiration either directly or indirectly. Suggested control substances are dinitrophenol or pentachlorophenol among organic compounds and arsenic (+3 valence state) among inorganic substances.

Procedures for the anaphase aberration bioassay are described by Kocan et al. (1982) and by Chapman et al. (1982c). Two cell lines are used in the assay, an experimental line cultured from rainbow trout gonad (RTG-2), which is sensitive to both mutagens and promutagens, and a control line of cultured bluegill fry (BF-2), which is insensitive to promutagens. Aqueous extracts of sediments should be prepared and stored frozen as described above for the oligochaete respiration bioassay. The aqueous sample can then be thawed and extracted organically as described by Chapman et al. (1982c). Cells cultured on glass slides are then exposed to a range of concentrations of the final extract, incubated for 48 h, fixed, stained and examined microscopically. A minimum of 100 anaphases per slide (3 replicate slides per concentration of extract) are then examined and the percent of normal and aberrant anaphases recorded. Again, appropriate positive and negative control substances should be used (Chapman et al. 1982c; Kocan et al. 1982). In the sediment dilution bioassays, extracts should be prepared from experimental and reference site sediments that have been mixed in the same proportions described for the amphipod bioassay.

Bioaccumulation and Pathology

The primary objectives of this study are to: 1) determine levels of tissue contamination and frequencies of pathological disorders in representative fish and invertebrate (i.e., crab) species in various subareas of Commencement Bay, 2) compare the prevalence of disorders among subareas, and 3) relate contamination and disease of organisms to sediment contamination. Emphasis is placed on obtaining data suitable for statistical analysis. Although a number of past studies have investigated contamination and disease in Commencement Bay biota (e.g., Malins et al., 1980, 1982; Gahler et al., 1982), sample sizes have generally been too small to adequately characterize and compare various subregions of the embayment, and to relate incidence of contamination and disease in biota to contamination of bottom sediments. Results of the recommended study will allow ranking of subareas based on degree of tissue contamination and disease, identification of local "hot spots," and evaluation of risk to public health from consumption of contaminated organisms.

General Study Design--

Chemical analyses of edible fish and crab tissue should be conducted throughout the study area and at reference sites. Fish livers should be examined for pathological disorders at all stations used for analysis of contaminants in edible tissues (muscle). The results from these pathological analyses should then be used to select a limited number of study sites for liver contaminant analysis. For each selected site, livers from diseased and healthy fish should be examined.

Using the results of the analyses described above, comparisons can be made between contaminated and reference sites to determine whether tissue contaminant levels and frequency of disease are significantly different between the two habitat types. Comparisons can also be made between contaminated sites to rank them according to impact on biota and to identify "hot spots" of contamination and disease. Finally, comparisons can be made between liver contaminant levels in diseased and healthy fish to estimate which contaminants may have caused observed pathological disorders.

Target Species--English sole (Parophrys vetulus) was selected as the representative fish species for several reasons. First, this species is abundant and widespread throughout Commencement Bay, enhancing the probability that adequate sample sizes can be obtained at all study sites. Second, English sole live in close contact with bottom sediments, prey mainly on small benthic infauna, and exhibit high levels of tissue contamination and disease in urbanized areas of Puget Sound (e.g., Malins et al., 1980, 1982). It is therefore likely that this species is being influenced by contamination of bottom sediments. Finally, because English sole is frequently captured and consumed by recreational fishermen, this species is part of a pathway through which contaminants can move from sediments to humans.

Pathological and contaminant analyses should be biased toward larger English sole (i.e., larger than 230 mm total length, or greater than 3 years old) for two reasons. First, larger fish are the ones most likely to be retained and consumed by recreational fishermen and therefore pose the greatest threat to public health if their edible tissue is contaminated. Second, frequency of pathological disorders in English sole livers increases with age (Malins et al., 1982). Biasing samples toward larger (i.e., older) fish should thus increase the numbers of diseased fish encountered and thereby ensure that adequate sample sizes are available for subsequent liver contaminant analyses.

Dungeness crab (Cancer magister) was chosen as the representative invertebrate species primarily because it has shown a tendency to accumulate contaminants in tissues that are consumed by humans. However, it is uncertain whether this species is sufficiently abundant throughout Commencement Bay to allow statistical comparisons between all study sites. It is therefore recommended that two additional species of cancrid crabs be sampled (i.e., C. gracilis and C. productus), and that subsequent contaminant analyses be conducted on the species that most closely matches the requirements of the study design.

Parameters--The parameters to be measured during the bioaccumulation and pathology study are:

Contaminants in Fish and Crab Muscle Tissue and Fish Liver

- Metals

- Base neutral organic compounds

- Volatile organic compounds (Hylebos and City Waterways and reference site only)

- Acid extractable organic compounds

- PCBs

- Pesticides

Fish Pathology

- External abnormalities for all biota (e.g., lesions, epidermal papillomas, fin erosion, parasites)

- Internal abnormalities for English sole

- Selected liver lesions for English sole

Ancillary Parameters

- Individual English sole
  - weight
  - length
  - sex
  - age

- Individual cancrid crabs
  - weight
  - width
  - sex

- Species composition (numerical) of trawl samples.

Volatile organic compounds should be measured in muscle and liver tissues at selected contaminated sites to confirm past data, which suggest these contaminants do not bioaccumulate in substantial quantities. The high cost of chemical analyses precludes determination of volatile organic compounds in all tissue samples.

The liver is singled out for pathological and contaminant analyses because it is the organ most closely associated with regulation and storage of many toxic chemicals (e.g., Fowler 1982). Also, for English sole in Puget Sound, the liver is the organ most heavily afflicted with pathological disorders (Malins et al., 1980, 1982). To enhance study efficiency, pathological analysis of livers should be restricted to the five types of idiopathic lesions found to be nonuniformly distributed in Puget Sound (Malins et al., 1982). These include neoplasms, preneoplastic conditions, nonspecific degenerative/necrotic lesions, specific degenerative/necrotic lesions, and intracellular storage disorders.

Ancillary data (weight, length, etc.) should be collected for all English sole in each trawl sample. Weight-length relationships for each sex can serve as "condition" indices (e.g., for comparisons among sites). Species composition of each catch should also be determined. These data will be used to characterize and compare fish assemblages. Collection of additional ecological data is not warranted because a specific sampling scheme, limited in time and space, has been designed to meet the primary objectives of the study.

Sample Sizes--To determine the desirable sample sizes for pathological analysis of English sole livers, 2x2 contingency analysis was conducted on three sets of data (Table 17). The question asked was, given a certain background level of disease (i.e., 0, 5, and 10 percent), at what point does an increase in sample size lead to a negligible improvement (i.e., <1.0 percent) in the ability to statistically discriminate an elevated level of disease. Results showed that for all three background levels, discriminatory improvement dropped below 1.0 percent when sample size exceeded 100. We therefore recommend that 100 fish be used for pathological analysis at each study site.

TABLE 17. DETERMINATION OF MINIMUM DETECTION LEVELS FOR ELEVATED INCIDENCE OF DISEASE GIVEN 10 SAMPLE SIZES AND THREE BACKGROUND LEVELS OF DISEASE[a]

Sample Size	Background Levels of Disease: 0 Percent %[b]	D[c]	5 Percent %	D	10 Percent %	D
20	20.0		30.0		40.0	
		10.0		10.0		12.5
40	10.0		20.0		27.5	
		3.3		3.3		4.2
60	6.7		16.7		23.3	
		1.7		1.7		2.0
80	5.0		15.0		21.3	
		1.0		2.0		1.3
100	4.0		13.0		20.0	
		0.7[d]		0.5[d]		0.8[d]
120	3.3		12.5		19.2	
		0.4		0.4		0.6
140	2.9		12.1		18.6	
		0.4		0.8		0.5
160	2.5		11.3		18.1	
		0.3		0.7		0.9
180	2.2		10.6		17.2	
		0.2		0.1		0.2
200	2.0		10.5		17.0	

[a] Comparisons were made using a 2x2 contingency formulation and the chi-square criterion.

[b] Minimum level of disease that is significantly different ($P<0.05$) from background levels.

[c] Difference in minimum detection levels between two consecutive sample sizes (i.e., improvement of discriminatory ability).

[d] D < 1.0 percent.

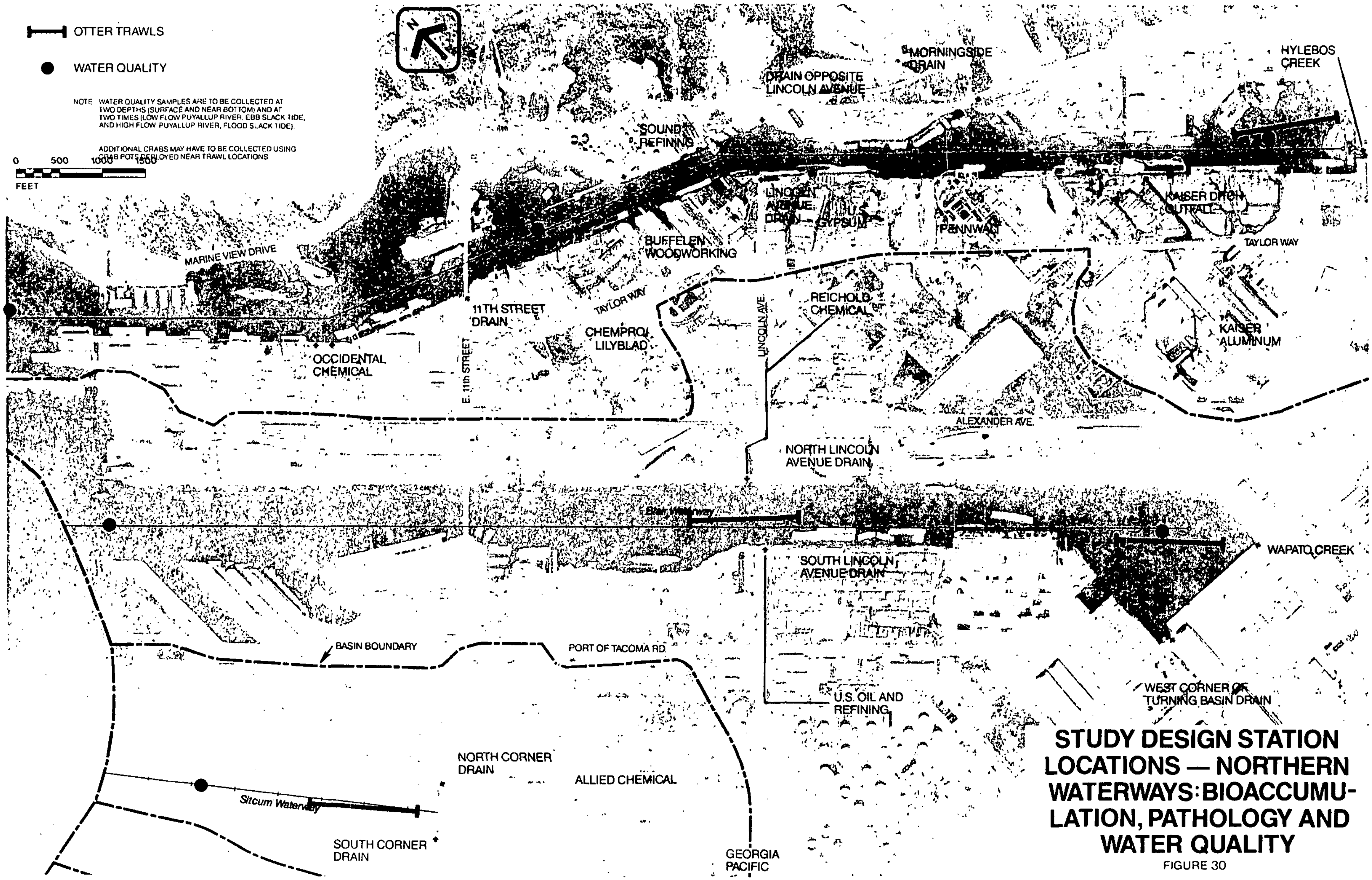
For contaminant analysis of edible tissue and livers, we recommend using a minimum of five fish and five crabs from each study site. This sample size is a balance between analytical costs and even representation across all stations. Gahler et al. (1983) used the same sample size to compare contaminant levels in muscles of English sole between Hylebos and City Waterways and Discovery Bay (a reference site). Tissue levels of PCBs were relatively high in the waterways and could be discriminated from those at the reference site site ($P<0.05$, Mann-Whitney U-test). However, levels of DDT were only slightly elevated in the waterways and could be discriminated from background levels only at City Waterway. These results suggest that a sample size of five may be adequate for discriminating large differences between contaminated and reference sites, but may be insufficient for discriminating smaller differences.

Station Locations--

Fishes and invertebrates should be sampled at 13 sites in the project area (Figure 25, 30, and 31) and at two sites in a reference area (Carr Inlet). The Puyallup Waterway should not be sampled because English sole are rarely captured there (Weitcamp and Schadt 1981). Sampling at a study site should consist of a trawl transect and a series of crab pots deployed off the adjacent shoreline.

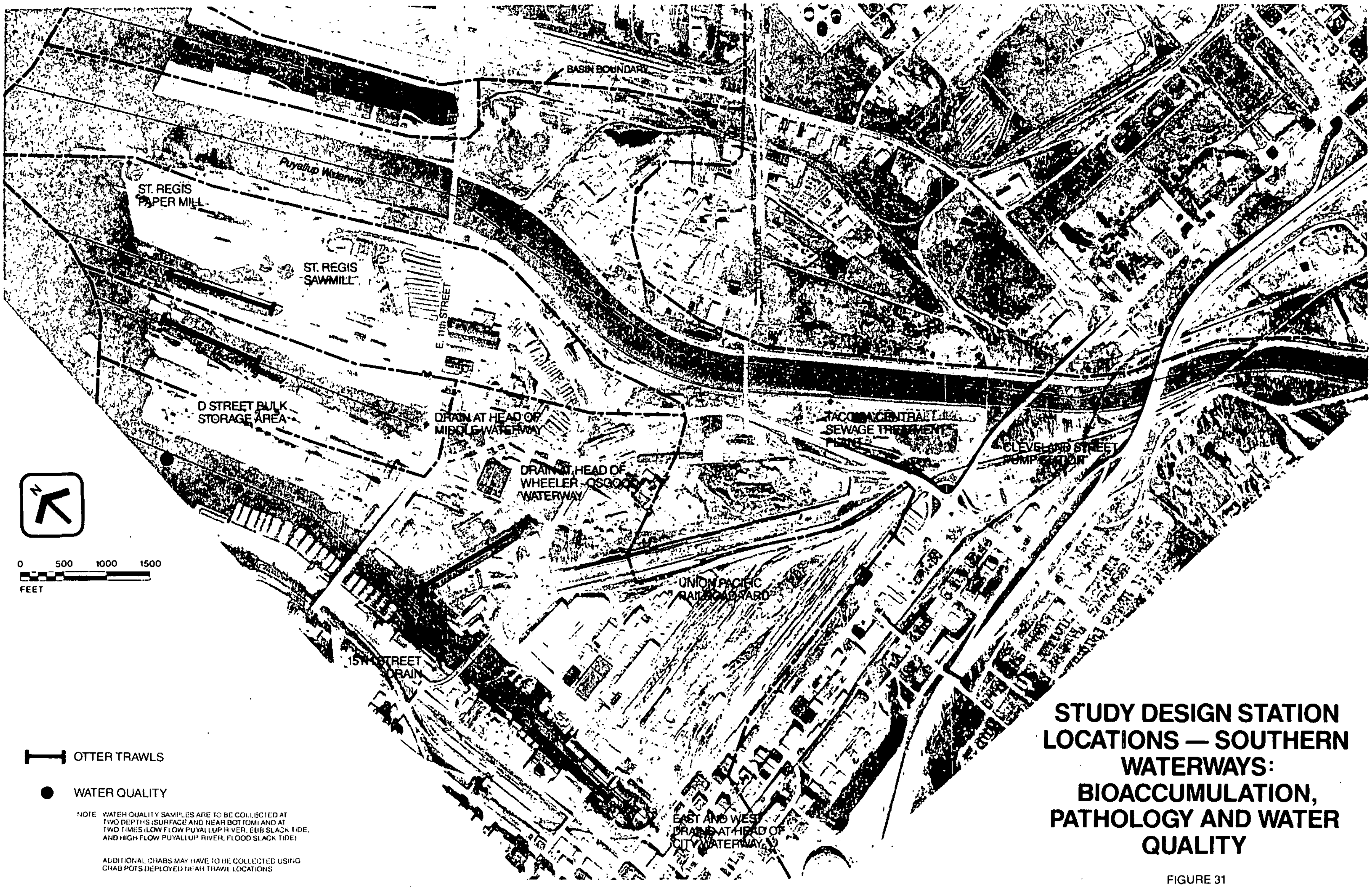
Study sites should be located near the head of each waterway to enhance the probability that captured organisms had spent a fair amount of time in the waterway before capture (i.e., they were not simply migrating through). A single transect should be used to characterize each smaller waterway (i.e., Sitcum, Milwaukee, St. Paul, and Middle). In the high priority waterways, two transects should be sampled, one near the head and one near a major source of contamination (i.e., Pennwalt Chemical Company in Hylebos Waterway, Lincoln Avenue drain in Blair Waterway, Wheeler-Osgood Waterway in City Waterway).

Three study sites should be located along the Ruston-Point Defiance shoreline. One should be located near Old Tacoma, where relatively high



STUDY DESIGN STATION LOCATIONS — NORTHERN WATERWAYS: BIOACCUMULATION, PATHOLOGY AND WATER QUALITY

FIGURE 30



STUDY DESIGN STATION LOCATIONS — SOUTHERN WATERWAYS: BIOACCUMULATION, PATHOLOGY AND WATER QUALITY

FIGURE 31

levels of polychlorinated biphenyls, chlorinated butadienes, and hexachlorobenzene have been found in bottom sediments (Malins et al., 1980). The other two transects should be located near the ASARCO smelter. One should be established directly off the discharge pipe and the other should be located midway toward Point Defiance, in a presumably less contaminated area. The latter transect will be used to estimate the spatial extent of contamination away from the smelter and toward the important recreational fishing areas near Point Defiance.

The two transects in the reference area should be established in two types of sedimentary environments likely to be encountered in the contaminated areas; namely, mud and fine sand. A preliminary survey is recommended to locate these study sites (see above, General Approach, Preliminary Survey).

Carr Inlet should be a particularly useful reference site for bioaccumulation and pathology studies. First, resident English sole appear to form a discrete stock, rarely migrating out of the inlet (Holland 1969). It is thus highly unlikely that these fish have ever been exposed to many of the contaminants present in Commencement Bay sediments. Second, English sole populations in Carr Inlet are very dense and exhibit characteristics (e.g., size distribution and sex ratio) similar to those observed for populations in Sitcum and City Waterways by Becker and Chew (1983). These population characteristics suggest that adequate sample sizes can be obtained in Carr Inlet and that resident fish are exposed to ecological surroundings similar to those of the Commencement Bay waterways.

Sampling Times--

To maximize sample sizes and thereby enhance the ability to discriminate spatial patterns of contamination and disease, we recommend that all sampling be conducted during a single season.

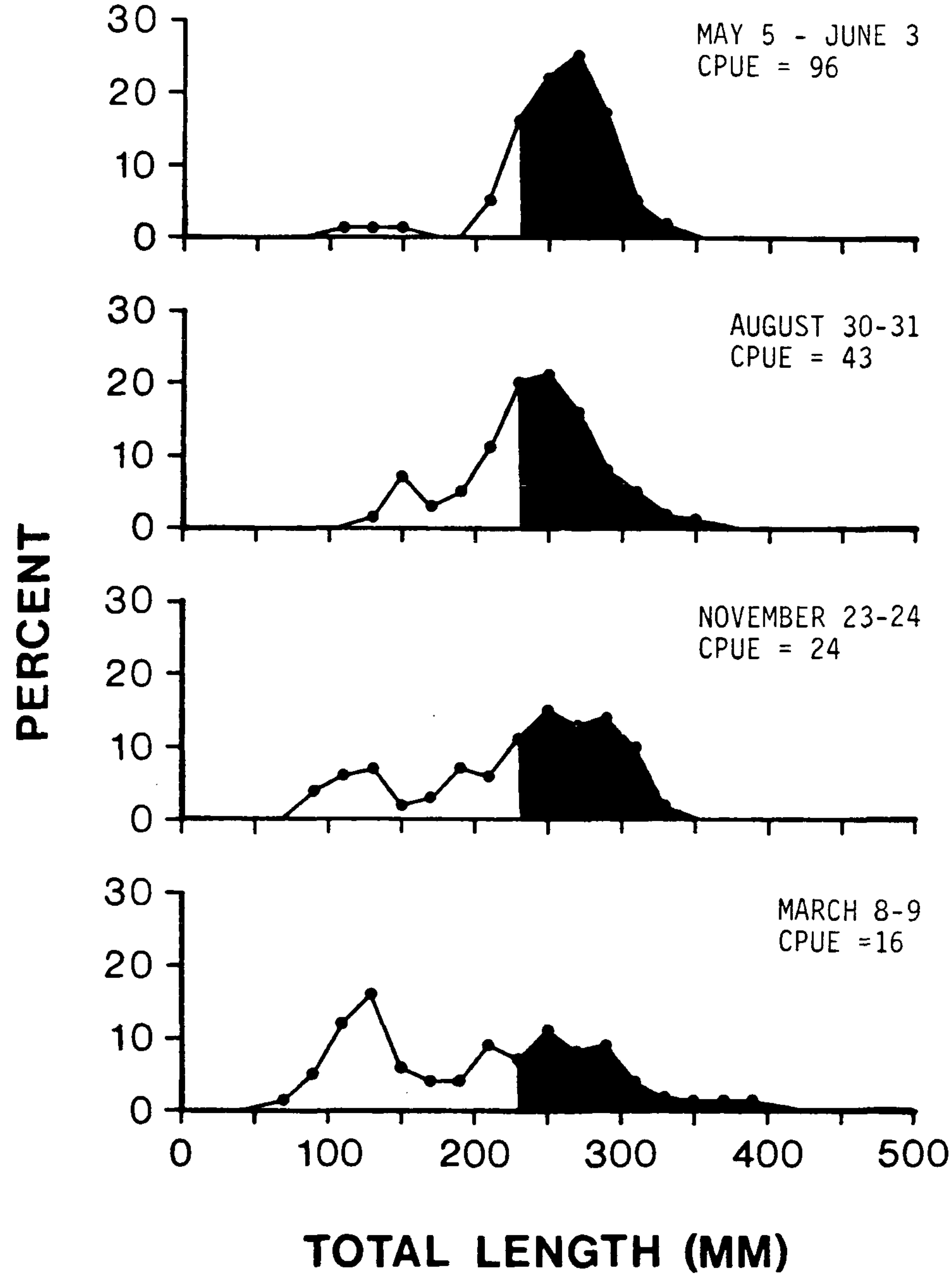
Given the seasonal variability of English sole abundance and size distribution in the nearshore region of Commencement Bay (e.g., Weitcamp and Schadt 1981; Becker and Chew 1983; Becker, in review), sampling efficiency can be maximized by sampling between early June and late August. That is, because larger fish migrate into the nearshore zone to feed during this period, catch rates of fish larger than 230 mm reach an annual peak (Figure 32), and fewer trawl samples should be needed to obtain required sample sizes.

A second reason to sample English sole between June and August is that fish are rapidly replenishing lipid reserves following winter fasting and subsequent spawning (review in Roff 1982). Tissue concentrations of lipophilic contaminants (e.g., chlorinated hydrocarbons) may therefore reach an annual peak (i.e., worst-case scenario) during this period. Also, because fish are actively feeding, probability of detecting unstable (e.g., biotransformable) liver contaminants is probably highest at this time.

Finally, because most recreational fishing presumably occurs during spring and summer, determination of contaminant levels in edible tissue during this period is probably the most meaningful method of assessing risk to public health from consumption of contaminated organisms.

The primary constraint to sampling fish in late spring or summer is that liver contaminant analyses cannot begin until results of pathological analyses are completed (i.e., to determine which waterways and fish to examine). However, if sampling is conducted in early June (at the earliest), pathological analyses could be completed by early September (Landolt, M., personal communication).

From a diel perspective, we recommend that all sampling be conducted between sunrise and four hours after sunrise. Becker and Chew (1982) found that trawl catches of English sole exhibit predictable diel patterns in the nearshore zone of Puget Sound, with catches being highest at dawn and dusk and lowest during mid-day and night. Sampling near dawn would increase catch rates and leave the rest of the day for sample processing or other activities. This scheme would also ensure that fish assemblages from all study sites are sampled during the same diel period and can thus be validly compared.



Blackened parts of size distributions represent contributions of fish larger than 230 mm. Catch per unit effort (400 m transect) of fish larger than 230 is indicated for each season. Methods are the same as those recommended in text. Modified from Becker (in review).

Figure 32. Seasonal size distributions of English sole captured in Sitcum and City Waterways and at Browns Point.

Sampling Methods--

English sole should be sampled using a 7.6-m (headrope) otter trawl having a body mesh size of 3.2 cm (stretched) and a cod-end liner mesh size of 0.8 cm. As this net has been used by other researchers in Puget Sound (e.g., University of Washington, National Marine Fisheries Service), data collected in the present study will be directly comparable with results of most past studies. Mearns and Allen (1978) describe the sampling device and its operation.

Trawls should be made at a constant vessel speed of approximately 1.3 m/sec (2.5 knots) and each transect should extend approximately 400 m (0.25 mi). Generally, a 5-min haul will cover the required distance, but this may vary depending upon strength and direction of currents. We recommend that transects be based on distance rather than time, to ensure that sampling effort is standardized.

In the waterways, transects should run parallel to the longitudinal axis of each water body and should be positioned at mid-channel. Transects along the Ruston-Point Defiance shoreline and in the reference area should be positioned along the 10-m (30-ft) isobath. A minimum of one haul should be made at each site. Additional hauls may be necessary to obtain required sample sizes.

Because trawling in Commencement Bay waterways is often complicated by snags and capture of bottom debris, we recommend using a polypropylene (i.e., floatable) retrieval line attached to a float at one end and to the cod end (by shackle) at the other end. This line allows the net to be pulled in a reverse direction, and generally frees it from snags and bottom debris without tearing it. We also recommend having two complete trawl assemblies onboard; including otter boards, bridles, and nets. An additional one or two nets (perhaps borrowed) may also be desirable.

Cancrid crabs should be sampled using commercial crab pots. Crabs captured when trawling should also be retained and later pooled with those from crab pots.

Sample Processing--

The recommended sample-processing scheme is illustrated in Figure 33.

After each trawl sample is brought onboard, the catch should be sorted into three categories: 1) English sole, 2) cancrid crabs, and 3) miscellaneous fishes and invertebrates. All organisms should be examined for grossly visible external abnormalities while being processed.

Cancrid crabs should be identified to species, counted, measured (carapace width), weighed, sexed, frozen whole, and stored for contaminant analysis of edible tissue. The same procedures should be followed for cancrid crabs captured in crab pots. Invertebrates other than cancrid crabs and fishes other than English sole should be identified to species and released.

All English sole should be measured (total length) and weighed. The body cavity of each fish should be opened, sex determined, and grossly visible internal abnormalities noted. One hundred fish larger than 230 mm should be randomly selected, and the liver and otoliths (sagitta) of each specimen should be removed. If 100 fish cannot be obtained from the initial trawl sample, additional hauls should be made until the required sample size is obtained. Otoliths should be stored for later age determinations.

After livers and otoliths have been removed, five of the 100 fish larger than 230 mm should be randomly selected, frozen whole, and retained for contaminant analysis of edible tissue.

From each of the 100 livers, a 1-cm^3 subsample should be excised, placed in 10 percent buffered formalin, and retained for pathological analysis. If a liver contains grossly visible abnormalities, the subsample should be taken at the border between the normal and abnormal tissue and should include both types of tissue. If no abnormalities are visible, the subsample should be taken from a random location.

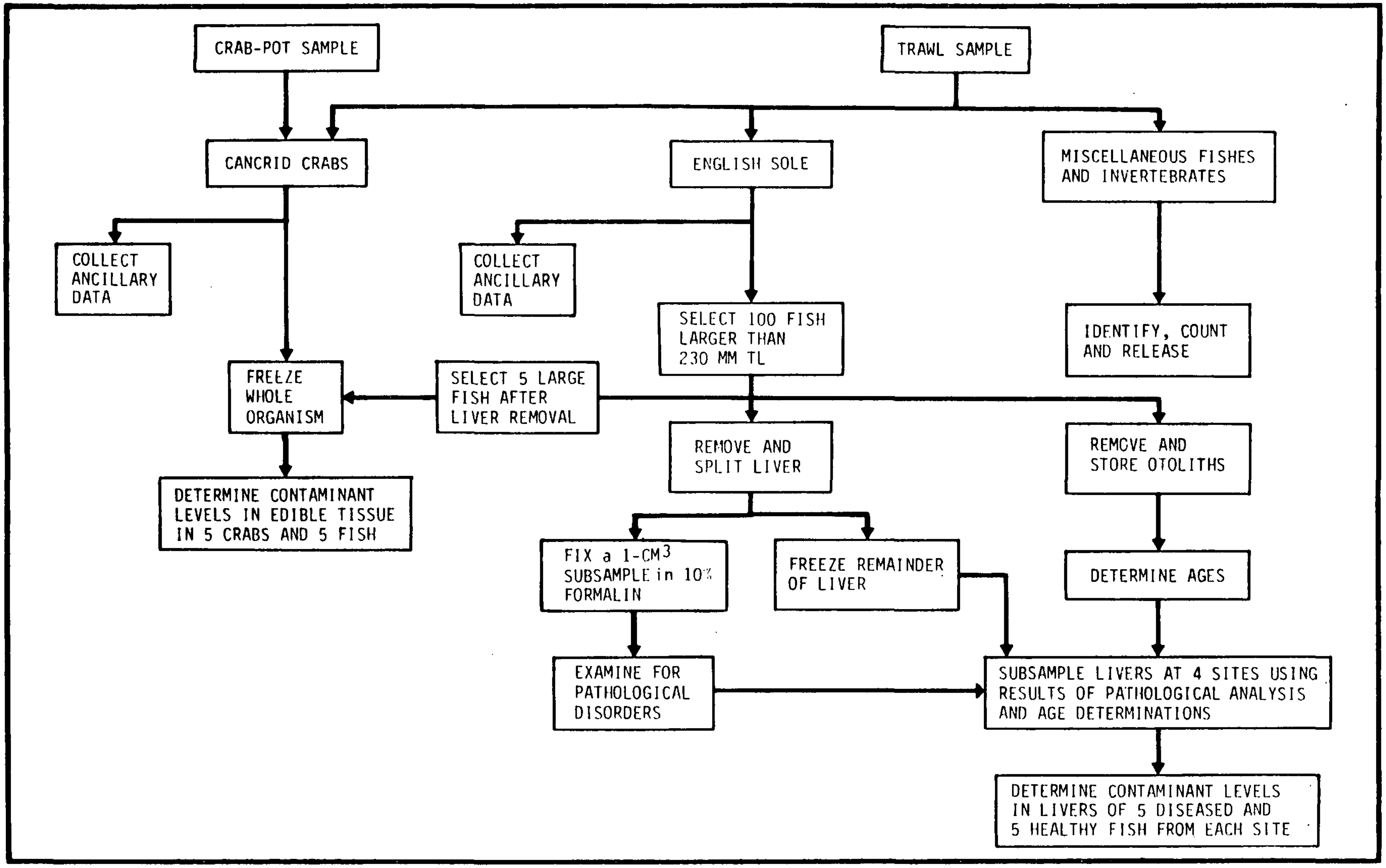


Figure 33. Sample processing scheme for pathology and bioaccumulation study.

The remainder of each liver (i.e., after the pathology subsample has been removed) should be frozen and stored for contaminant analysis.

Following pathological analysis of the 100 livers from each site, five diseased livers (or composites) and five healthy livers (or composites) should be selected from four study sites. As pathological disorders appear to be age-dependent, diseased and healthy livers should represent similar age distributions. Moreover, composites should include only fish of the same age.

The four study sites selected for liver contaminant analysis should consist of the reference area and three contaminated areas. Which contaminated areas to examine should be determined primarily from the frequencies of pathological disorders observed in this study.

Water Quality

The water quality study recommended here is designed to characterize the water masses, suspended particulate matter, and associated contaminants transported into and out of the Commencement Bay waterways at the extremes of a range of hydrologic conditions. Information derived from this study will fill a major data gap for the entire waterways system. For Milwaukee and Middle Waterways information on priority pollutant concentrations in the water column will be obtained for the first time.

Considerable data collected over a wide range of sampling areas and times are necessary to establish links between water contamination and bioaccumulation. Temporal coverage is especially important since contaminant concentrations in tissues are the result of long term uptake and accumulation. Collection of such a large data set is beyond the scope of the present study. However, data collected as part of the program recommended here will add to the existing data base (see above, Data Evaluation), which may be useful for examining relations between water quality and tissue contamination (CA Objective 9).

General Study Design--

Determination of water column parameters at the mouths of the waterways under different hydrologic conditions will provide information on the relationship among circulation processes, contaminant concentrations, and intertransport of materials between Commencement Bay and the waterways. Stations should be positioned at the mouth of each waterway to ensure sampling at the interface between the waterway and the Bay. By sampling at extremes of river flow, the influence of the Puyallup River plume in the system can also be estimated. Thus, sampling should be conducted once at ebb slack tide when the Puyallup River is at low flow (July), and once at flood slack tide when the Puyallup River is at high flow (March). The high-flow sampling period should coincide with northerly transport of the river plume. These sampling times will ensure that a wide range of hydrologic conditions is bracketed. Two depths should also be sampled: the "brackish" surface layer and the middle of the saline bottom layer. Concentrations of volatile organic compounds, HCBD, and PCBs are expected to be highest in surface samples, whereas other contaminants (e.g., naphthalene) may be present in higher concentrations in deeper water (Riley et al., 1981). Since past water quality studies in the project area have not characterized vertical distributions of contaminant concentrations sufficiently, sampling at a minimum of two depths is necessary. Because the scope of this study is limited, sampling of more than two depths is probably not justified.

By sampling at ebb tide/low flow, the worst-case influence of pollutant sources on the Bay will be estimated. Waters draining from a waterway should exhibit maximum concentrations of contaminants under these conditions. Conversely, sampling at flood tide/high flow will provide data on maximum influence of Bay waters and the Puyallup River plume at the mouth of each waterway.

The parameters to be measured during the water quality study are:

<u>Priority Pollutants - Filtered Water</u>

- Metals

- Volatile organic compounds
- Chlorinated organic compounds

Priority Pollutants - Particulate Matter

- Metals
- Base neutral organic compounds
- Acid extractable organic compounds
- PCBs
- Pesticides

Conventional Pollutants

- Total suspended solids
- Particulate organic carbon

Ancillary Parameters

- Salinity
- Temperature
- Dissolved oxygen
- Location of Puyallup River plume.

Characterization of priority pollutants in filtered water is desirable for quantification of available chemical forms and comparison with EPA Water Quality Criteria. Since only metals, volatile organic compounds, and chlorinated organic compounds (e.g., PCBs and CBDs) have been found in significant concentrations in filtered water in the study area (Riley et al., 1981; Isakson and Loehr 1981), the analyses of the filtered water sample should be restricted to these contaminant groups. The particulate fraction should also be analyzed because: 1) the biological availability of contaminants bound to particles may be low relative to dissolved forms of the same contaminants, 2) contaminants bound to suspended matter represent the major form of contamination in the water column for most priority pollutants, and 3) the composition of suspended matter can be compared with sediment contamination data to infer transport pathways between water and bottom sediments. Since volatile organic compounds are not expected to associate strongly with suspended matter, volatile contaminants need not be measured in the particulate fraction.

Measurements of total suspended solids and particulate organic carbon will yield information on sediment transport processes in relation to the influence of the Puyallup River plume on the waterways. Also, organic contaminant concentrations will be normalized to organic carbon content of the samples. The location of the Puyallup River plume should be documented at least during each sampling period (and more frequently if possible) by standard aerial photographs or LANDSAT images.

Station Locations--

Locations of sampling stations specified for the water quality study are shown in Figures 25, 30, and 31. The primary stations for examining water quality in relation to bay/waterway transport phenomena (i.e., temporal comparisons at each station) are positioned at the mouths of Hylebos, Blair, Sitcum, Milwaukee, and City Waterways. Comparisons among stations at the mouths of waterways will elucidate the spatial distribution of contamination, and the influence of the Puyallup River. Additional stations within Hylebos, Blair, and City Waterways are positioned to allow spatial characterization of contaminant and suspended particle distributions within each waterway. The goal here is to estimate the average properties of a water mass, not to characterize receiving waters for point sources. Therefore, all stations are located away from known sources of pollution. Comparisons among or between stations within a waterway will provide further information on flushing characteristics of the system. At a given point in time, homogeneity of water properties within a waterway indicates efficient flushing of the waterway by bay waters. Conversely, a heterogeneous distribution suggests a longer flushing time, and a potential for greater local influence of point sources within a waterway.

Sampling Methods--

At each station, a water column profile of salinity, temperature, and dissolved oxygen should be obtained by probe measurements at 1-m intervals (for depths less than or equal to 8 m), and at 2-m intervals (for depths greater than 8 m). Two of the profile depths should coincide with the sampling depths (surface and bottom-layer midpoint).

Water samples should be collected at each depth, using either a 20-l, teflon-lined water bottle (Van Dorn sampler or similar device) or a suitable water pump sampler. Because of the large water volumes necessary for analysis of some contaminants, a water pump will be more convenient. Samples should be collected at a discrete point in time (ebb slack or flood slack tide) on a given sampling date. Thus, more than one sampling vessel will be required. Although temporally-composited samples would provide a characterization of average conditions, there are two disadvantages to a time-integrated sampling scheme: 1) additional manpower and funds are necessary for sample collection, and 2) changes in the water chemistry of stored samples over time cannot be assessed. Moreover, standard methods would limit the total storage time to approximately 1 week.

Sample Processing and Analyses--

Processing and analyses of water samples are summarized in Figure 34. Based on previous investigations in the study area (Riley et al., 1980, 1981), a minimum of 80 ml of whole water should be collected for analysis of purgable organic compounds. Riley et al. (1980, 1981) sparged and analyzed 35 ml of the 80 ml sample and stored the remaining fraction as a "contingency" sample. The remaining analyses should be conducted on water filtered through a 0.45 um filter or the particulate matter retained on the filter. Approximately 1 l should be filtered for analysis of total suspended matter. A total of 8 l of filtrate will be required for analysis of dissolved metals (Carpenter, R., personal communication) and 20 l for selected organic pollutants (Riley et al., 1981). These sample sizes are larger than those suggested by EPA guidelines. Detection limits are inadequate for PCBs using EPA Method 608 with only 1 l of sample. However, detection

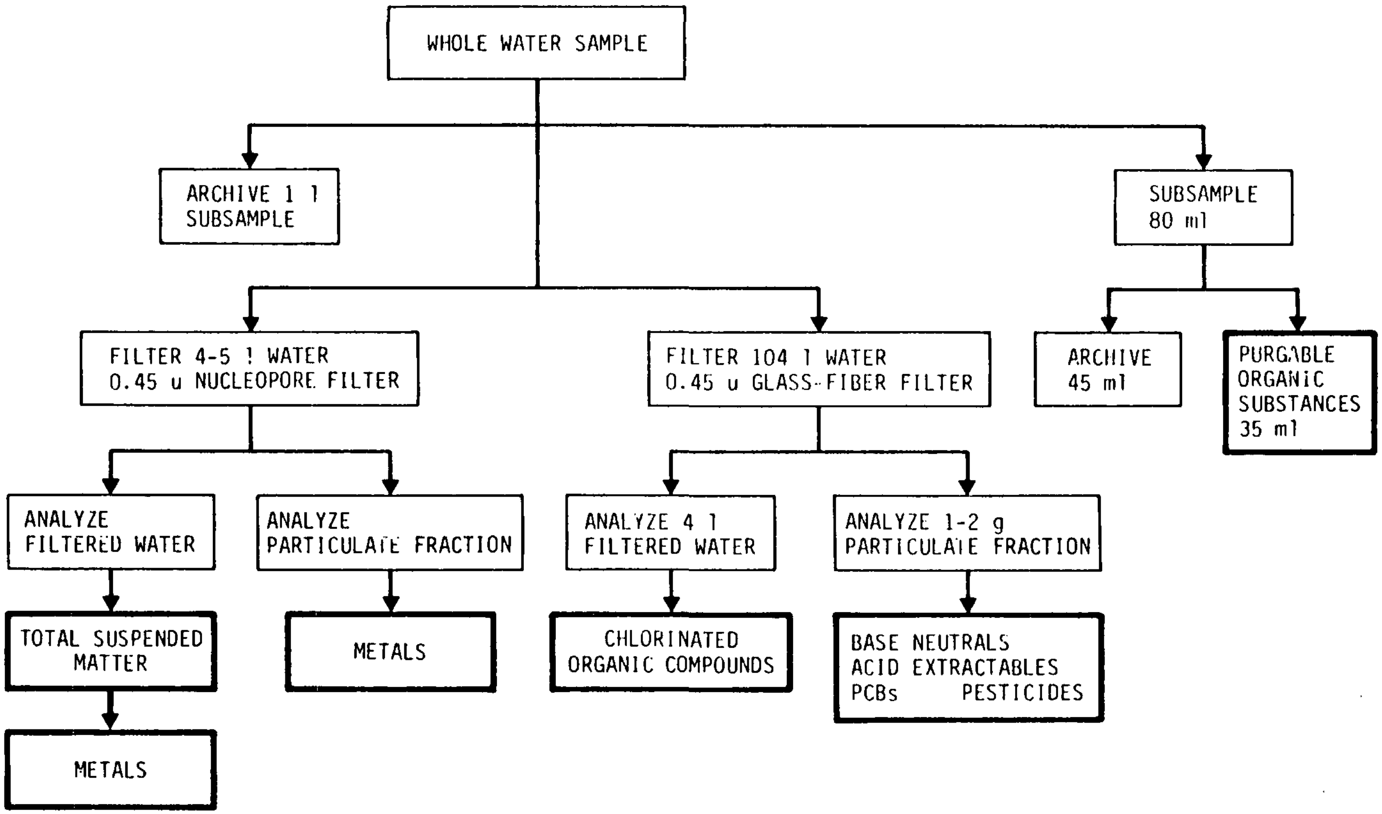


Figure 34. Sample processing scheme for water quality study.

limits of the EPA methods are inadequate for this project. For example, many of the PCB Aroclors could not be detected using EPA Method 608 and only 1 l of sample (U.S. EPA 1979b).

Analysis of organic pollutants in suspended particulate matter requires filtration of an exceptionally large water volume. Riley et al. (1981) sampled 20 l of water in their study. However, this sample size should be regarded as an absolute minimum. Since only about 2-10 mg/l were present at the time of their sampling, Riley et al. (1981) used only 0.04-0.2 g of material for their analyses. At the lowest contaminant concentrations, (e.g., 10 ng/g of particulate-associated contaminant), this sample size yields only 0.4-2 ng of contaminant for analysis. Pavlou et al. (1983) analyzed organic pollutants associated with suspended particulate matter in the main basin of Puget Sound. Initial studies by Pavlou et al. (1983) indicated that a sample size of 400 l (with about 2-3 mg/l suspended matter) was inadequate for the low background concentrations of toxic organic compounds present in Puget Sound waters. Pavlou et al. (1983) then developed a system capable of filtering 40,000 l of water in 4.5 h, producing 10-20 g dry weight solids for analysis. Quantitation limits for acid and base neutral extractable compounds on suspended matter ranged from about 80-7,000 ppb with this sample size. Most pesticides and PCBs could be quantified at 0.2-1 ppb.

Values of about 2-20 mg/l for suspended matter are anticipated in the study area (Baker and Walker 1982; Riley et al., 1981). Since filtration of extremely large water volumes is impractical for the recommended study, it may be necessary to accept high detection limits for contaminants associated with suspended particles. An initial sample volume of about 100 l is suggested as a minimum for this study. With 10 mg/l suspended matter and a low concentration of 1 ng/g of contaminant, this sample size would yield 1 g of solids and about 1 ng of contaminant for analysis. It is recommended that sampling methods and the adequacy of this sample size be confirmed during the preliminary cruise.

SUMMARY

A summary of spatial coverage and sampling effort for the preliminary study design is provided in Table 18. The timing of each individual survey is discussed in an earlier section (see General Approach, Study Types, and Program Integration). Note that deep core samples in Blair Waterway will be collected as part of a sediment study conducted by the Port of Tacoma to characterize sediments scheduled to be dredged for development of a containerized cargo facility.

The preliminary study design has been developed to provide a comprehensive assessment of contamination and effects within the study area. The objective has been to maximize information gain relative to preliminary estimates of program cost and available funding resources. It is recognized that following detailed cost evaluation, the projected program costs may exceed available funds thereby requiring reductions in sampling intensity. In such cases, the following cost saving reductions should be considered. The cost saving alternatives are ranked so that the initial items are those with the lowest overall information loss relative to cost savings.

1. Reduction in number of deep core stations in Hylebos Waterway and Ruston Shoreline (total reduction of up to 20 sediment samples)

2. Reduction in sediment layers analyzed in deep cores following analysis of sub-bottom profiles

3. Deletion of trout cell toxicity from bioassay studies

4. Deletion of multiple stations used for fish and crab samples in Hylebos, Blair, and City Waterways (total reduction of 30 tissue samples)

5. Reduction in number of English sole used for pathology studies to 60/site (total reduction of 600 pathology samples).

TABLE 18. SUMMARY OF PRELIMINARY STUDY DESIGN

	Study Components											
		Sediment Quality				Bioassay[c]			Bioaccumulation[d]		Water Quality	
Area	Runoff Sources	Preliminary Survey	Main Survey	Deep Core	Infauna Community Structure[c]	Undiluted	Dilution Series	Fish Pathology[d]	Muscle	Liver	Core Elutriate	Water Column
Hylebos	1	3	36	5	14	14	2	2	2	1	2	3
Blair	3	4	26	11[a]	6	6	1	2	2		11[a]	2
Sitcum			5	2	3	3	1	1	1	1	1	1
Milwaukee		1	4	1	3	3		1	1			1
St. Paul			5	1	4	4		1	1			
Middle		1	3	1	1	1		1	1			
City	2	3	8	3	6	6	1	2	2	1	1	2
Ruston Shore		3	20	5	9	9		3	3		1	
Commencement Bay			4									
Reference		4	4		4	4		2	2	1		
Total No. Stations	6	19	115	29	50	50	5	15	15	4	16	9
Total No. Samples	6	19	115	145[a,b]	250	50[e]	5[f]	1500	150[g]	40[h]	80[a,b]	54[i]

[a] Eleven cores to be taken as part of Port of Tacoma sediment dredging study.

[b] Five vertical interval samples per core.

[c] Benthic infauna community structure stations, bioassay stations, and fifty sediment quality stations coincide.

[d] Pathology and bioaccumulation samples to be taken from same trawls.

[e] Subsamples of five replicate sediment samples at each station to be composited.

[f] Subsamples of four replicate sediment samples at each station to be composited. Four dilutions per sample.

[g] Five crabs and five fish at each station.

[h] Five pathological livers and five normal livers at each station.

[i] Two depths, two sampling periods, and two fractions (dissolved, particulate) at each station.

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